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Paul T. Tueller, R. Douglass Ramsey, Thomas D. Frank, Robert A. Washington-Allen, Scott Tweddale, Randall S. Karalus, Carolyn T. Hunsaker, Laura E. McCarthy, Thomas G. Van Niel

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Corps of Engineers
Topographic Engineering Center
7701 Telegraph Road
Alexandria, VA 22315-3864

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SERDP
901 North Stuart St. Suite 303
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Emerging and Contemporary Technologies in Remote Sensing for Ecosystem Assessment and Change Detection on Military Reservations

INTERIM REPORT

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Paul T. Tueller, R. Douglas Ramsey, Thomas D. Frank, Robert A. Washington-Allen, Scott Tweddale, Randall S. Karalus, Carolyn T. Hunsaker, Laura E. McCarthy, and Thomas G. Van Niel

Abstract

Extensive land areas and environmental questions on military landscapes suggest the need for procedures for identifying and monitoring the fundamental vegetation and soil attributes quickly and efficiently. This study is an effort to: 1) evaluate emerging and contemporary remote sensing technology for examining plant succession; 2) determine ecosystem response and recovery in relation to disturbance and degradation through retrospective studies with spatially-explicit spectral-based indices; 3) identify spatial, spectral and temporal attributes of remote sensing systems necessary to identify ecotones and improve vegetation mapping; and, 4) develop methods for upscaling indices between coarse and fine resolution imagery. Land degradation can be defined as: (1) a change in plant species composition; (2) a decrease in plant productivity; (3) a reduction in soil quality; (4) accelerated soil erosion, and (5) a change in landscape composition and pattern that affect ecological function. The behavior near or at critical thresholds of these five characteristics of land degradation provide a diagnostic basis for the development of remote sensing-based indicators to estimate ecosystem sustainability. An important goal is to incorporate data into land based carrying capacity models as well as detecting and monitoring change. We are currently developing algorithms for improved and more efficient image processing of large (50 - 100 image) contemporary satellite datasets. These algorithms will also be incorporated in the decision support system developed for the Army National Guard called the National Environmental Database (NED) at Utah State University. Data from space platforms shows promise for mapping landscapes and identifying ecotones. Near-earth, large-scale multispectral airborne videography with submeter pixels is being evaluated to identify and quantify species or species guild composition across ecotones and along degradation gradients. Field measurements show that many plant species can be identified and upscaled to the vegetation polygons developed during the mapping process. Five hierarchical levels of classification are being tested: (1) Seral Stages within a plant community, (2) Plant communities along an environmental gradient, (3) Dominant Species along an environmental gradient; (4) Dominant Species, and (5) Dominant Life Form.

Management Structure

The CS-1098 SERDP Research Project is a FY 1998 new start. The project combines the resources from two separate original proposals as requested by the SERDP Executive. The approved research proposal was submitted under the SERDP FY98 Statement of Need number CSSON5 -- Landscape Level Change Detection to Support Carrying Capacity and Analysis for Military Ranges. This research effort will be coordinated by the U.S. Army Corps of Engineers' Topographic Engineering Center (TEC). The effort involves three Universities and two additional government labs, including: University of Nevada, Reno (UNR); Utah State University (USU); University of Illinois, Urbana Campus (UIUC); Oak Ridge National Laboratory (ORNL); and, U.S. Army Corps of Engineers Construction Engineering Research Laboratory (CERL). TEC engaged the efforts of the universities through a mutually agreeable "Cooperative Agreement." TEC retained the services of ORNL through a 'MIPR' and mutually agreeable "Statement of Work." CERL's participation was established through an intra-departmental transfer of funds. Dr. Carolyn Hunsaker of the Forest Service is a participating researcher through an agreement between ORNL and the Forest Service.

Although each researcher is a primary contributor to the project, the Principal Investigator is considered to be Dr. Paul Tueller of UNR. The Co-Principal Investigator is Dr. Robert Douglas Ramsey of USU. These two represent the lead investigators on the original two proposals merged by direction from SERDP. Dispersal of all funds for the Project will be made to the U.S. Army Corps of Engineers' Topographic Engineering Center (TEC). TEC is responsible for the dissemination of project funding and coordination.

1.0 Project Coordinator: Randall S. Karalus (CETEC-TR-G)
U.S. Army Corps of Engineers
Topographic Engineering Center
7701 Telegraph Road
Alexandria, VA 22315-3864
TEL: 703-428-7251
FAX: 703-428-6425
E-Mail: karalus@tec.army.mil

1.1 Financial POC: Debra Richardson (CETEC-RM)
U.S. Army Topographic Engineering Center
7701 Telegraph Road
Alexandria, VA 22315-3864
TEL: 703-428-6618
FAX: 703-428-8176

2.0 Technical POC: Dr. Paul T. Tueller
Department of Environmental and Resource Sciences
University of Nevada Reno
1000 Valley Road
Reno, Nevada 89512
TEL: 775-784-4053
FAX: 775-784-4583
E-Mail: ptt@equinox.unr.edu

3.0 Technical POC: Dr. Robert Douglas Ramsey
Department of Geography & Earth Resources
College of Natural Resources
Utah State University
Logan, Utah 84322-5240
TEL: 435-797-3783
FAX: 435-797-4048
E-Mail: doug@rsgis.nr.usu.edu

4.0 Technical POC: Robert A. Washington-Allen
Ecologist/Remote Sensing and GIS
Environmental Sciences Division
Oak Ridge National Laboratory
P.O. Box 2008, Building 1507, MS 6407
Oak Ridge, TN 37831-6407
TEL: 423-241-5159,
FAX: 423-574-4665 (at USU: 1-435-797-3796),
E-Mail: obq@cosmail2.ctd.ornl.gov

5.0 Technical POC: Dr. Thomas D. Frank
Department of Geography
University of Illinois
220 South Mathews Street
Urbana, Illinois 61801
TEL: 217-333-7248
FAX: 217-333-7248
E-Mail: frank@gis.uiuc.edu

6.0 Technical POC: Scott Tweddale (CECER-LL-N)

U.S. Army Corps of Engineers
Construction Engineering Research Laboratory
PO Box 9005
Champaign, IL 61826-9005
TEL: 217-398-5219,
FAX: 217-373-4520,
E-Mail: tweddale@cecer.army.mil

7.0 Technical POC: Tom Van Niel

Department of Forest Resources
College of Natural Resources
Utah State University
Logan, UT 84322-5215
TEL: 435-797-0741
FAX: 435-797-4040
E-Mail: tvn@nr.usu.edu

8.0 Others: DEQ Fort Bliss: Dallas Bash

DEQ Camp Williams: Dr. John Crane

SERDP Relevance

The research proposed here addresses the Department of Defense's (DOD) Strategic Environmental Research and Development Program's (SERDP) interest in research on Conservation priority 4, particularly, the development of landscape-level change detection methods using emerging remote sensing technologies and traditional field measurements to detect change in vegetative cover and secondary succession.

DoD has military bases with over 25 million acres of land. Of that, 11 million acres are training lands under Integrated Training Area Management (ITAM). Today's training and testing needs lead to changes in the ecosystem that may exceed the current estimated annual cost of $56 million in land repair and maintenance. DOD has a need to better characterize and quantify the carrying capacity of DOD land resources to support military training and testing. Hence, DoD has a need for efficient tools, models, and techniques to better characterize and quantify the carrying capacity of land resources to support military training and testing. Land-based carrying capacity (LBCC) is the ability of specific land parcels to accommodate training, testing, and mission activity. The Office of the Deputy Chief of Staff for Operations and Plans (ODCSOPS) defined the requirement for carrying capacity as: "Installation training managers need to identify carrying capacity of training lands, predict the impacts of land based usage, understand risk associated with use, analyze decisions to provide training flexibility versus environmental or ecological damage". The need for "efficient tools, models, and techniques to characterize, integrate constraints and quantify the capability of DOD lands and natural resources to support the military training and testing missions and other appropriate uses on a sustained basis" is DOD Conservation requirement priority 4.

These procedures help managers predict the impacts of land-based usage, understand the risk associated with use, and analyze decisions to provide training flexibility versus environmental or ecological damage. Examples that meet conservation requirement priority 4 and thus fulfill such needs include: the National Environmental Database (NED), the Army Training and Testing Carrying Capacity (ATTACC) model, and, the Ecological Dynamics Simulation (EDYS) model. These modeling efforts require reliable techniques and data which come from field-based measures, such as those derived from DoD's Land Condition and Trend Analysis (LCTA) data sets, and from biophysical models derived from remote sensing. By incorporating both environmental and training characterization, models such as ATTACC have been developed by DOD to calculate the land rehabilitation/management costs associated with different vehicles and training activities by incorporating both environmental and training activities. The LBCC plant community dynamics simulation models are based upon secondary succession. The models are species-level stress response models based upon existing field data, literature, greenhouse and garden plots, and field scale experiments to quantify mechanisms that control secondary succession, including independent field validation plots.

Objectives

The objectives of this project are to: stratify the landscapes of individual military ranges using contemporary and emerging remote sensing technologies; identify the fundamental vegetation and soil attributes of military ranges as they relate to plant succession; establish ecosystem response and recovery in relation to disturbance (land use) through retrospective studies with spatially-explicit spectrally-based indices; identify the spatial, spectral and temporal attributes of remote sensing systems necessary to identify ecotones, and to distinguish along environmental and disturbance gradients, and lastly; develop methods for scaling indices between coarse and fine resolution imagery.

Changes in environmental conditions can potentially change dominant patterns and species composition, effectively changing the habitat (Tausch et al, 1993). Plants serve as indicators where precipitation is scarce and irregular. They can indicate such factors as moisture, soil type, and salinity. Some plants may indicate different conditions in different areas. Land use on fragile arid ecosystems, and the resulting change, can potentially be measured with remote sensing techniques, allowing managers to remotely monitor and, thus, maintain ecological and biological integrity -- biological productivity, soil stability, species diversity, and native plant communities vigor (Tueller 1995). This research is designed to develop remote sensing techniques to relate ecological concepts of carrying capacity, vegetation dynamics, critical thresholds, habitat fragmentation, ecosystem response and recovery, and land degradation to the response of spectral indicators, and ultimately to training and testing upon military installations. The proposed research will apply change detection methods, both spatial and temporal, over a range of geographic scales using contemporary and emerging remote sensing technologies and traditional field surveys to identify and monitor vegetative cover and secondary succession. **Emerging remote sensing technologies** are panchromatic, multispectral, and hyperspectral airborne and satellite sensors and their digital products, and government and commercial imaging systems, such as Ikonos, HYDICE, and Flight Land Videography, which will become available during the life of this proposed project. Emerging remote sensing technologies have primary relevance to this proposal in terms of their temporal, spatial and spectral resolution. **Contemporary remote sensing technologies** are readily available commercial platforms, such as the Landsat Thematic Mapper (TM), Multispectral Scanner (MSS), SPOT, IRS, and aerial photography, that provide historical data for retrospective change detection studies. Historical remote sensing imagery provides a time series or repeat sampling record of particular study sites. The following chart presents a sampling of the contemporary and emerging remote sensing systems under study.

Land degradation can be defined in terms of ecological endpoints: (1) a change in plant species composition: (2) a decrease in plant productivity; (3) a reduction in soil quality; (4) accelerated soil erosion; and (5) a change in landscape composition and pattern that affect ecological function. The behavior near or at critical thresholds of these five characteristics of land-degradation provide a diagnostic basis for the development of remote sensing-based indicators to estimate ecosystem sustainability. Spectral indicators derived from these endpoints measure the response to training activities on military installations. These spectral indices will be derived from historical, contemporary, and emerging remote sensing technologies, and

calibrated by traditional field measurements.

Sensor Chart

	Spatial Resolution meters(m)	Spectral Resolution (*u*m)	No. of bands
CONTEMPORARY			
Landsat			
Multispectral Scanner (MSS)	80	0.5-1.1	4
Thematic Mapper (TM)	30	0.45-1.25	6
	120	2.08-2.35	1
SPOT			
Panchromatic	10	0.51-0.73	visible B&W
Multispectral	20	0.50-0.89	3
Standard Aerial Photography (e.g., NAPP)			
	variable	0.47-0.73	visible color, B&W
	variable	0.500-0.88	Color Infrared
Digital Aerial Orthophotography	variable	user-defined	user-defined
EMERGING			
IRS-1C			
Indian Remote Sensing Satellite ()			
Panchromatic	≤ 10		
Linear Imaging Self-Scanner	23.5	0.50-0.59	3
	70.8	1.55-1.75	1
Wide Field Sensor	188	0.62-0.86	2
HYDICE*			
Hyperspectral Digital Imagery Collection Experiment	variable	0.40-2.50	206
CASI*			
Compact Airborne Spectrographic Imager	variable	0.40-1.00	up to 39
AMS -- Daedalus 3600*			
Airborne Multispectral Scanner	variable	0.42-12.5	10
IKONOS 1			
Space Imaging	1	-	visible
CAMIS	variable	0.35-0.90 (variable)	4
KODAK DCS 420 Color infrared video camera	variable	RGB	3

(* — Acquisition costs can be considerable. Limited to available data. New acquisition is planned for only one of the initial study sites in the out-years.)

Technical Approach

The technical approach for this project is essentially a composite of: (1) mapping the installation or select components thereof; (2) correlating the fundamental attributes of disturbance and plant succession; (3) analyzing, retrospectively, the ecological history of each installation in relation to land use, and; (4) assessing high resolution systems to identify the sensor attributes necessary to monitor changes in plant species composition along disturbance gradients and plant succession stages. The researchers will examine vegetation indices, spectral unmixing and the use of ancillary data, e.g., DEMs to aid in the interpretation of the remotely sensed data. The research will take place over four years at up to four research/military facilities. Sites were chosen for their representation of several important ecoregions, training regimes, and the availability of both GIS/remote sensing data and Range Facilities Management Support System (RFMSS) data. For the first year, the sites are Camp Williams, Utah (Cold Intermountain Desert) and Ft. Bliss, Texas (Chihuahuan Hot Desert). The potential out year sites include Ft. Hood, Texas (Central Prairie and Plains) and 29 Palms, California (Mojave Hot Desert). The proposed research will be conducted within a GIS framework. Change detection modules, related imagery, and spectral libraries will be integrated into appropriate GIS frameworks.

Landscape scale mapping of installations or select component thereof will provide maps which identify areas of change or disturbance that need further investigation with high resolution remote sensing systems. Mapping units will be created based upon botanical composition and related land cover characteristics. The mapping and stratification campaign will occur during peak wet and dry seasons. Contemporary satellite imagery will identify and map landscape level communities associations. Progressively higher spatial and spectral information will be analyzed to stratify the landscape into defined mapping units. The mapping units will represent community types defined by carrying capacity models, such as LCTA and LBCC, and to the classification systems used by other federal agencies. Very high spatial resolution imagery will also be acquired along sample transects. From coincident field and image data, empirical relationships will be developed between field data and high resolution imagery. Five hierarchical levels of classification are to be tested: (1) Seral Stages within a plant community; (2) Plant Communities along an environmental gradient; (3) Dominant Species along an environmental gradient; (4) Dominant Species, and: (5) Dominant Life Form.

Table 1. Hierarchical Classification Scheme for Map Units

.	Seral stages within a plant community
.	Plant communities along an environmental gradient (e.g., soils, precipitation, etc)
.	Dominant species along environmental gradients
.	Dominant species
.	Dominant life form (e.g., tree, shrub, grass, etc.)

Fundamental attributes of disturbance on military ranges will be studied as they relate to plant succession. Vegetation surveys, soil and substrate analysis, and site condition scoring for two disturbance categories - highly disrupted and non-disrupted - will be conducted. Evaluation of levels of vegetation and soil disturbance will allow the creation of a sampling gradient that includes both vegetation cover and soil disturbance. Emerging technologies (involving spectral de-mixing, vegetation indices, and multiple resolution imagery) relating remotely sensed data to ecological parameters, will be used to correlate imagery to measures of seral stages. Calibration will allow extrapolation over larger geographic regions. Calibration will be through hybrid calibration cover-radiance models and spectral mixture modeling (Pickup et al. 1993). The influence of soil type is critical in areas where vegetation densities are low and numerous soils offer complex spatial patterns. Soil maps will be used to relate spectral response to soil classification units.

The **retrospective study** will use wet and dry season anniversary imagery. Remotely sensed **indices of land degradation** will be derived from satellite data. These indices will relate to a site's ecological resilience and critical thresholds, i.e., response and recovery from disturbance, vegetation cover; plant species composition; soil geomorphology; albedo; and landscape diversity, composition, shape, and pattern. Historical remote sensing imagery will be chosen to represent a typical year for each site, and anniversary peak wet and dry seasons. The image data sets will be rectified and normalized. Vegetation maps will be created for each period -- classified by dominant life form. Bare ground class will be refined by albedo maps. Acquired RFMSS and other land management data will be used characterize the land disturbance. Spectral indices of land degradation will be derived from historical, contemporary, and emerging remote sensing technologies, then calibrated with traditional field measurements. The indices will relate to a site's ecological resilience and critical thresholds. The threshold represents the point where significant change in plant species composition occurred. A multi temporal GIS analysis environment will be develop where an empirical test of landscape threshold dynamics developed in both range and landscape ecology can be tested. Topographic models will be created to identify sinks, sources, and transfer areas, as well as watersheds and sub-basins. These, in turn, will be statistically-related to the soil and vegetation indices.

This study will seek to distinguish spectral changes due to phenology and changes in important species composition caused by disturbance. Spectral signatures associated with

different phenological expressions will be examined for several dates and related to species composition for the same dates. In this way the changes in ecotonal boundaries and associated plant communities can be related to either phenological changes or changes in species composition.

Table 2. Characteristics of resilience and examples of their application adapted from Westman (1985).

Characteristic	Definition	Example
Inertia	Resistance to change	fenced area or grazing pressure required to affect change in % plant cover
Elasticity	Rapidity of restoration of a stable state following disturbance	time period required to return to 70% plant cover
Amplitude	Threshold, zone (multi-dimensional) from which a system will return to a stable state	In a 2-D analysis the magnitude of the dependent variable e.g., % plant cover and the independent variable, e.g., grazing frequency
Hysteresis	Degree to which the path of restoration is an exact reversal of path of degradation	degree to which the recovery of plant cover is not an exact reversal of the pattern of decline
Malleability	Degree to which the stable state established after disturbance differs from the original steady state	% plant cover before grazing frequency compared % plant cover after grazing frequency changes

A **range of spectral, spatial, and temporal resolutions** will be evaluated to determine the capability to differentiate features in the landscape. The research will focus upon the requisite information necessary to identify and map the previously defined levels of hierarchy. Determination of specific plant communities with characteristic botanical composition will require the use of emerging remote sensing technologies (e.g., IKONOS, HYDICE, DMSV) in combination with spectral and textural classification procedures. From coincident field and image data, empirical relationships will be developed between field data and high resolution imagery. To relate landscape composition and pattern to changes in soil and vegetation parameters, and anthropogenic inputs, FRAGSTATS, a spatial analysis program, will be used. Algorithms can then be developed to calibrate and 'scale up' from high resolution to coarse resolution imagery. This will be accomplished by developing linear models relating surrogates of range condition to the larger land areas.

Table 3. Sensor attributes necessary to differentiate features in the landscape hierarchy (see Table 1)

	Seral Stage	**Plant Community**	**Dominant Species/ Environmental Gradient**	**Dominant Species**	**Life Form**
Spatial Resolution					
Spectral Resolution					
Temporal Resolution					
Spatial Scale					

Benefit

The project will provide DoD managers efficient tools, models, and techniques to better characterize and quantify the carrying capacity of land resources to support military training and testing. Being able to estimate ecosystem sustainability, managers can predict the impacts of land-based usage, understand the risk associated with use, and analyze decisions to provide training flexibility versus environmental or ecological damage. This project will provide: 1) models and tools for change detection of land use on military reservations; 2) methods for scale transitions; 3) an understanding of relationships between a hierarchy of spatial and spectral resolutions across ecotones or along degradation gradients, and; 4) a better understanding of ecosystem response and recovery in relation to disturbance (land use) as measured on a landscape scale with remote sensing.

Significant resources are expended to develop models or systems such as: the National Environmental Database (NED), the Army Training and Testing Carrying Capacity (ATTACC) model, the Ecological Dynamics Simulation (EDYS) model, and the Land Management System (LMS). These models/systems require reliable techniques and data which come not only from field-based measures, such as those derived from DoD's Land Condition and Trend Analysis (LCTA) data sets, but also from biophysical models derived from remote sensing. The techniques resulting from this project (and the data) will contribute to the success of these other programs.

SAB "Action Items":

SERDP to assess benefit of conducting a retrospective analysis;

The idea of **carrying capacity** of vegetation and soil resources applied to military training activities is derived from concepts in range science, where there is a need to balance livestock grazing of vegetation resources and disturbance of soil against the ability of these resources to recover (Warren and Bagley 1992). However, ecologists have questioned both the assumption of equilibrium in the carrying capacity concept and its definition and utility for management of landscapes (Bartels *et al.* 1993). These questions have focused specifically on the predictability of vegetation productivity and succession. The current theory of vegetation succession is that vegetation dynamics are dependent on initial conditions that are likely to diverge on a number of different trajectories depending on autogenic (e.g., regular phenological changes) and allogenic processes (e.g., disturbance). Thus, these vegetation dynamics may be less predictable than previously thought (Pickett and McDonnell 1989, Sprugel 1991). This has shifted the focus from prediction to explanation of the behavior of those processes that alter ecological systems at or near critical thresholds of land degradation (Schaeffer and Cox 1992). Desert landscapes are often described as being fragile because of their susceptibility to erosion, low turnover of bases, little accumulation of litter and slow recovery of vegetation and soil after disturbance. Thus, loss of habitats which may be altered by land management practices can potentially affect a large number of species and change landscape biodiversity (Noss 1983).

A critical threshold is defined as the boundary in space and time between two seral states, e.g., the observed changes of grassland to predominantly woody vegetation (Archer 1989, Friedel 1991). Military reservations are subject to a number of different land-uses (e.g., grazing and forestry), varied climatic disturbances (e.g., drought and tornadoes), and military training activities whose cumulative and separate effects need to be distinguished. Land managers often have a different perception of thresholds that is primarily influenced by ecosystem management and economic considerations. From their perspective, a critical threshold is the point where the initial shift across the boundary is not reversible on a practical time scale without substantial intervention of cultural inputs, e.g., herbicides, heavy machinery, or fire (Archer 1989, Friedel 1991). **Here is where the retrospective analysis plays its role**, to explain and model the behavior of processes at the critical thresholds of the ecological systems. Given an understanding of an ecosystem's dynamics under human influence, allows managers to effect some type of mitigation before the threshold is reached or passed; and, allows managers to control pending training thus preventing a catastrophic shift in the ecosystem. At or before the threshold, the ecosystem is capable of recovering, with maybe relatively minor anthropogenic manipulation. Otherwise, once beyond such a threshold, a significant and more costly intervention is demanded because the ecosystem is no longer capable of self-regeneration and recovery. Such thresholds can ultimately determine whether the facilities effect some minor or major initiative to mitigate impacts, e.g., closure of an area and minor regrading versus regrading, replanting and constant monitoring to prevent invasive, rudimentary species from dominating.

The impact of land-use change is a dynamic process in time and space. Consequently, analyses are required which can aid in identifying and delineating different habitats, and describe their changes in space and time. Remote sensing from satellite platforms is a technology with this capability; remote sensing provides the ability to analyze large areas (e.g., a 180 km x 180 km area/image is covered by the Landsat TM image), to sample repeatedly over long periods (Landsat satellites have sampled twice monthly for a 24 year period), and to view the landscape with a vertical perspective. Processed multi-temporal satellite imagery, coupled with the spatial analysis capabilities of Geographic Information System (GIS), can distinguish different habitats and dynamically map how they change in space and time and therefore provide insight into the effects of land-use change and natural disturbance on landscapes (Noss 1983, Stoms and Estes 1993). Therefore, if habitat use by individual species can be inferred then risks to biodiversity can be calculated.

The retrospective approach becomes a very powerful analysis when used in conjunction with adaptive resource management. A high priority in adaptive management is the maintenance of ecological integrity while managing for the sustainability of important human uses of ecosystems (e.g., military training). Information is gathered about the landscape (i.e. monitoring), analyzed, and then used to adapt management practices. So, environmental monitoring (i.e. retrospective analysis) is the crux of proactive management. Without monitoring, a land manager is forced to react to environmental scenarios. In general, monitoring programs accomplish two fundamental objectives: (1) provide a baseline against which land managers and decision makers can compare future inventories as they continue to monitor land conditions; and (2) evaluate the effectiveness of management activities. To date, the first of

these has been the focus of large comprehensive natural resources monitoring programs. However, it is the second objective that will take monitoring beyond simply a requirement of environmental compliance and make it a part of adaptive resource management in support of the military training mission. Ground data (e.g., LCTA) is based on point sampling which is then extrapolated over large polygons whereas remote sensing data looks at entire polygons which can be analyzed in total. This is the advantage of using remotely sensed monitoring (retrospective analysis) and the only way that this sort of analysis can be done.

The remote sensing technology approach is a proactive management technique wherein the landscape is monitored over time. The decisions made during such monitoring will allow a beneficial trade off between higher cost ground vegetation sampling and lower cost image processing analysis of remotely sensed data. Although good ground sampling data will always be required, the time necessary to capture the inherent heterogeneity of a landscape is substantial. (Bastin et al.,1993) using a field-based assessment of land condition when compared to a remote sensing /field-based hybrid method. Bastin et al. (1993) found that both ground-based and remote sensing-based methods detected degradation similarly, but that the remote sensing method cost substantially less than the field method. The assessment's costs were similar in the first year, but were substantially reduced in the second year for remote sensing. The primary cost of remote sensing was equipment acquisition, setup, and training. The primary cost of field-based assessments was in labor as related to the sampling design necessary to establish statistical confidence. Thus remotely sensed data in conjunction with a cogent assessment design is a valuable adjunct to existing and contemporary ground data.

A detailed example of a retrospective study being conducted for the Environmental Protection Agency by USU is included in appendix 1. This example is using some of the same basic methodology we are using in the SERDP retrospective analysis. The benefits shown will be much the same for SERDP.

-***<u>FY99 or FY00 tasks to include detailed plan of how individual DoD sites would use and implement results of the project</u>***.

Aspects of this question have been addressed in the first SAB action item *("SERDP to assess benefit of conducting a retrospective analysis")* and the TTWAG action items below. The primary purpose of our research has been to develop remote sensing-based change detection protocols for monitoring the effects of military training activity on a landscape's ecological integrity. These protocols are viewed as supplemental to field-based survey protocols developed for DoD facilities, in particular the LCTA program. Yet, this section's question addresses the problem of technology transfer of these protocols to each DoD facility. Major concerns of transfer of this particular technology to each facility include 1) the presence or absence of computer hardware and 2) trained natural resource oriented GIS/remote sensing personnel; and 3) the type of platform and 4) software used by each facility. In FY 98, we have partnered with two facilities at Camp Williams, Utah and Fort Bliss, Texas. Both facilities are well equipped for software and hardware with trained personnel in natural resources management fields and the use of GIS and remote sensing technology at the level of Masters Degrees (and PhDs). Both bases have computer facilities, software, and hardware specifically tasked for GIS and remote sensing operations. Camp Williams has benefited from its association with Utah State University through the LCTA and NGB National Environmental Database Project (NED). These programs

have allowed Camp Williams to move from the data collection/inventory stage to the analysis stage. However, the same can not be said for all DoD facilities. Few facilities may actually have all the components mentioned to have or even launch a successful monitoring program. To compensate some facilities have followed the Camp Williams model and successfully partnered with Universities. Other facilities have contracted with environmental consulting agencies and non-profits (e.g., the Nature Conservancy) and partnered with other federal agencies to provide the infrastructure previously mentioned.

Our partners will receive the change detection and uncertainty analysis protocols for remote sensing imagery which we have been incorporating into Environmental Systems Research Institute's (ESRI) GIS program ArcView. We are including all programs as extensions to the standard ArcView graphical user interface (GUI). The development of ArcView extensions simplifies technology transfer because ESRI software is almost platform independent and the user already has the GUI setup so no data manipulation is required. This allows for easy transfer of programs to DoD facilities and allows for the flexibility of the user to maintain his/her own GIS database. Major concerns with technology transfer usually include difficulty with customization of each facilities database. By using ESRI extensions, we can avoid this problem and make a great deal of this research readily available to any DoD site almost regardless of computer hardware and user skill level.

As for implementing results of our research, the facilities would use the analysis protocols developed in the retrospective study in conjunction with field surveys (i.e., the LCTA program) and data derived from both contemporary and emerging remote sensing platforms to establish a baseline and for continuing ongoing monitoring. We envision that aspects of the data from both the retrospective study and studies related to the emerging technologies will be incorporated into both EDYS and ATTACC models. EDYS is used to predict future conditions given a particular disturbance regime. Data from the retrospective analysis can serve to validate these predictions by comparison of the effects of past disturbances. By gaining knowledge of landscape dynamics in relation to training activities, through the retrospective analysis, land managers can adapt environmental inputs to the ATTACC model. Using emerging technologies, higher spectral and spatial resolution data implementation into EDYS and ATTAC models is also covered in detail in TTAWG Action item number 2 (*"PI should discuss transition/technology transfer to ongoing DoD land management modeling efforts (ATTACC, LMS) and the ultimate users").*

PI to ensure coordination with EMAP as described in coordination plan is implemented.

During FY98, the Project Coordinator worked with the SERDP office to acquire the Scientific Advisory Board's and the TTAWG's "Action Items" resulting from presentations to both. One "Action Item" with some impact to the SERDP project was the Board's request to coordinate with EPA's Environmental Monitoring and Assessment Program (EMAP). The SAB requested a formal "Coordination Plan." In response, information about EMAP was collected by several researchers. Then, discussions with the EPA EMAP personnel were initiated by Dr. Hunsaker of the Forest Service. A "Coordination Plan" was written (and submitted early April). The coordination is to be primarily handled by Dr. Hunsaker, who in turn, is working with EPA's

EMAP personnel. The SERDP research group is now discussing a more formal approach to the EMAP Coordination effort.

TTAWG "Action Items":

-PI is asked to quantify potential management payoff/cost-benefit and discuss specific new science in light of recent innovations.

This action item is answered in the TTAWG action item discussed above in regard to the retrospective study. Once again, the remotely sensed data provides a way to monitor the large land areas involved. These data then, can enter into land management practices and restoration projects, for example, by explaining and modeling the behavior of processes at critical thresholds of the ecological systems. Given an understanding of an ecosystem's dynamics under human influence, allows managers to effect some type of mitigation before the threshold is reached or passed; and, allows managers to control pending training thus preventing a catastrophic shift in the ecosystem. At or before the threshold, the ecosystem is capable of recovering, with maybe relatively minor anthropogenic manipulation. Otherwise, once beyond such a threshold, a significant and more costly intervention is demanded because the ecosystem is no longer capable of self-regeneration and recovery. Such thresholds can ultimately determine whether the facilities effect some minor or major initiative to mitigate impacts, e.g., closure of an area and minor regrading versus regrading, replanting and constant monitoring to prevent invasive, rudimentary species from dominating. Management payoff also occurs due to coordination of this research with existing models as explained in the next section discussing technology transfer to ongoing DoD land management modeling efforts.

Recent innovations in technology give us the use of new sensors such as Interferometric Synthetic Aperture Radar (IFSAR) to acquire higher resolution DEM's to feed models requiring topography. We would also like to take advantage of the sensor under development by the Air Force combining low light video, mid-infrared, and eight lidar sensors to potentially get information on species through chemical signatures and cryptogram detection if this becomes available. Similarly, hyperspectral sensors can potentially detect chemical signatures (species/cryptogram) better.

-PI should discuss transition/technology transfer to ongoing DoD land management modeling efforts (ATTACC, LMS) and the ultimate users.

Transition/technology transfer has been discussed in SAB action item regarding "FY99 or FY00 tasks to include detailed plan of how individual DoD sites would use and implement results of the project". The remotely-sensed change detection protocols developed through this effort will be targeted for incorporation into the Community Dynamics Simulation Models (CDSM) and other models. CDSM is user friendly executable software that runs within a PC/windows environment. The community dynamics simulation model (CDSM) is executable software that contains the scientific information, databases, and protocols necessary to simulate the natural dynamics (fluctuations) of the major plant/soil communities or ecosystems of an installation over temporal and spatial scales of interest to Army trainers and land managers. The community dynamics simulation model directly applies to the ATTACC model by providing

improved measures and predictions of land condition and improved relationships between training impact or load and land condition recovery.

Military installation land managers are responsible for managing military lands in support of the training and testing mission, while also complying with local, regional, and national environmental laws. A major challenge to military trainers and land managers is the allocation of training activities among different areas within an installation that appropriately balances training objectives and costs with environmental stewardship and constraints. In general, the goal of land managers and trainers is to allocate training activities in such a manner as to not exceed the "carrying capacity" of training lands at which unacceptable degradation begins to occur. Tools are required which allow land managers to evaluate different training allocation scenarios and make more informed training allocation decisions.

In response to this requirement, the Army Training and Testing Area Carrying Capacity (ATTACC) model has been developed by DOD to calculate the land rehabilitation/management costs associated with different vehicles and training activities by incorporating both environmental and training characterization (Price, et al., 1997). Erosion status and species composition have been identified as being the most critical measures of land condition on military installations. Therefore, as a sub-component of environmental characterization for ATTACC, Land Based Carrying Capacity (LBCC) researchers are currently developing and refining the Ecological Dynamics System (EDYS) model to simulate ecological dynamics on training and testing lands (Childress, McLendon, and Price, 1998). EDYS is a plant community dynamics simulation model based upon secondary succession. The components of EDYS under development are species-level stress response models based upon existing field data, literature, greenhouse and garden plots, and field scale experiments to quantify mechanisms that control secondary succession, including independent field validation plots.

Two primary tasks to be performed by the EDYS system are: 1) to allocate training activities among different areas in an installation in a cost-effective manner while meeting training needs for military readiness and minimizing ecological impacts, and 2) to serve as a tool for natural resource managers to evaluate outcomes over time of various stressors, natural and anthropogenic, on the ecosystems within an installation. The overall model design for EDYS implements a hierarchical system of modules which incorporates different ecological processes at different spatial scales. The model will run simulations of the impact of actual or proposed training disturbance regimes and the recovery process over time scales of one week to 100 years or more and over spatial scales from the species level to landscape levels. The EDYS model must operate at the scale at which training lands are managed, which is typically a training area. However, the hierarchical design allows the model to work at different scales, including the small scale of individual plant species. Even when the model is run at the landscape scale of an installation training area, it is still important to understand the dynamics which occur within the component larger scale systems within the landscape. By functioning at the large scale of individual plant species, the model can adequately represent changes in ecosystem function and dynamics as species composition changes with succession, disturbance, and invasion. (Childress, McLendon, and Price, 1998)

The EDYS model directly applies to the ATTACC model by providing improved measures of the environmental costs of conducting the training and testing mission. Both

ATTACC and EDYS modeling efforts require reliable techniques which combine advanced imaging technologies (remote sensing) and traditional field measurements to detect change in vegetative cover and secondary succession on military installations. The ability to accurately assess and predict both erosion status and changes in species composition (community dynamics) relative to training load will significantly improve the corresponding factors of the ATTACC model (Price, et. al., 1997). It is estimated that these improvements will provide training managers the information to improve utilization of training lands by 30% and not exceed the carrying capacity beyond their current ability to rehabilitate or maintain the land at the desired condition status.

However, for the EDYS model to reach it's full potential as both a resource for installation land managers to assess different training allocation scenarios and as an input into ATTACC, the model must be run within a spatial context. In order to accurately simulate future community composition within a spatial context, it is critical to provide accurate and detailed maps of initial community composition into the model. Currently, such maps do not exist because of limitations in the spectral and spatial resolution of commercial imagery that has been available for mapping vegetation and the high costs associated with detailed ground surveys of large installations. Results from this research, which includes analysis of emerging airborne and satellite data with higher spatial and spectral resolutions, will include procedures for mapping vegetation at a an appropriate scale and level of detail necessary to initialize and then simulate ecological dynamics within EDYS. This information will be critical to the extrapolation of EDYS results over training areas or across entire installations. In addition, the procedures developed in this research will also provide a foundation for conducting change analysis across subtle environmental and degradation gradients. This information may be critical in allocation of future training loads so as to not exceed an installation's carrying capacity, or capacity to sustain the training mission. These same change detection techniques are also critical to calibration and validation of the EDYS model.

Remotely-sensed change detection products will be fully demonstrated, validated, and implemented within the CDSM framework, and would be available for implementation at other installations at the completion of this effort. Technology transfer will occur via scientific and technical literature and CD-ROMS prepared as a part of this study with specific information for each study location.

Leveraging

Historical Analysis of Land Cover/Condition Trends at Ft. Bliss, TX Using Remotely Sensed Imagery

(Project Cost 100K)

Goals/Objectives:

1) Establish relationships between remotely sensed data and estimates of vegetative cover
2) Assess relative, temporal trends in land condition using remotely sensed spectral indices
3) Observe spatial patterns of change in land condition using remotely-sensed spectral indices, and
4) Compare trends and patterns for impacted vs. non-impacted study sites.

Spectral Demixing for Sub-Pixel Quantification of Land Cover at Ft. Bliss, TX

(Project Cost 430K)

Goals/Objectives:

1) Evaluate CIR photography as a surrogate for in-situ measurements of vegetation cover , and
2) Evaluate Spectral Demixing as a method to extract detailed estimates of vegetative cover from coarse resolution imagery and extrapolate these estimates installation wide

Mojave Database project

The Mojave project was a 3 year contract that cost 2.5 million shared between the United States Geologic Survey (USGS) and USU. The database consists of ecoregion-wide (+50km buffer) mosaics of the Desert as defined by Bailey. These mosaics include 3 MSS mosaics (NALC) 1 TM mosaic (all Landsat mosaics are radiometrically calibrated), 30m digital elevation data, 500m climate grids including 30 year normals for every day of the year (maximum and minimum temperature, precipitation, and potential evapo-transpiration), AVHRR 10-day composites for 1990-1995, general vegetation (GAP), bedrock geology, soils (STATSGO), hydrologic units, cartographic layers, Digital Raster Graphics, and an annotated spatially referenced bibliography consisting of over 18,000 citations of literature and cultural features in the Mojave Desert.

National Environmental Database (NED) Program

NED has been in action since 1993 costing an estimated 800k-1million/yr. USU has signed a sole-source agreement for an additional 5 years for a maximum of 15 million dollars. The 15 million dollars is in anticipation of other government agencies wanting to pass work though this contract vehicle. Our first year budget has run approx. $800k. Camp Williams has benefited from the initial first 5 years of the NED program since it has been one of the model sites for GIS and graphical user interface development. NED's funding agency is the National Guard Bureau. The initial contract was to develop GIS databases for 54 national guard installations nation-wide.

Characterization of the Ecological Integrity of Commercially Grazed Rangelands Using Remote Sensing-based Ecological Indicators (EPA/USU)

The project is funded from 11/10/97 t0 11/09/99 for $341K. The goal of this project is to develop ecological indicators of rangeland condition and trend (ecological integrity or health) at landscape and sub- to regional scales derived from remotely sensed satellite imagery, particularly Landsat MSS and TM. We, SERDP, leverage these funds on our SERDP project by use of the USU range ecology lab's advanced computing facilities funded by EPA and use of image processing algorithms developed for this project and housed at this facility.

The ORD/NCERQA EPA project is about $200,000 FY 98 and $141,000 FY 99. What is leveraged by SERDP from this project is:

1. Robert Washington-Allen, 2 months ($10,000/mth x 45% overhead x 2 =)
2. USU Range Ecology Lab Computer use and storage ($1600/mth x 2 month)

So approximately
$32,200 is being leveraged for FY 1998.

Camp Williams Project - Utah Army National Guard (UTARNG)/Utah State University (USU)

The SERDP project also benefits form previous work done by UTARNG and USU at Camp Williams. Particularly useful to the SERDP project is use of satellite imagery, floristic survey (including TE survey), soils work, fire history and fuels inventory, Land Condition Trend Analysis monitoring, vegetation studies on military ranges, range utilization studies and extensive GIS database development. A brief summary of projects and estimated costs to UTARNG and USU follows.

Description	Cost to UTARNG & USU
Computer lab access	$ 4,800
Satellite Imagery (TM & MSS)	$ 10,000
Floristic & Faunal Surveys	$110,000
Soil Survey and Analysis	$ 60,000
Plant Communities Studies	$ 35,000
Fire History and Fuels Inventories	$ 90,000
Cougar/Mule Deer Interactions	$ 35,000
Vegetation Mapping	$ 1,600
LCTA Monitoring	$ 75,000
GIS Development	$180,000
LCTA Analysis	$ 20,000
NGB/WES	$ 50,000
NGB/NRCS	$ 50,000

National Guard Bureau (NGB)/ Waterways Experiment Station (WES)

This contract is for approximately $1.8 million to produce wetlands maps for some 35 national guard installations including Camp Williams. The estimated cost for the Camp Williams work is $50,000. The work is planned for the summer of 1999.

NGB/Natural Resources Conservation Service (NRCS)

A soil survey has been completed at Camp Williams in FY98 by the NRCS. The product will be delivered in FY99. The estimated cost is $50,000.

Sensor Optimization Program

Includes assessment of multi-scale, multi-resolution remote sensing systems. **1)** assessing the capabilities of existing spacecraft platforms (SPOT, Landsat, Earthwatch/Space Imaging, Intelligence Systems) for terrain data requirements (vegetation, transportation, surface drainage, soils/surface materials, obstacles), **2)** comparing current data products to emerging capabilities (HYDICE, IFSAR, AMPS, Lewis), and **3)** developing automated data integration and feature attribution methods.

Study Sites

<u>Fort Bliss, Texas</u> (Satterwhite and Ehlan, 1980)

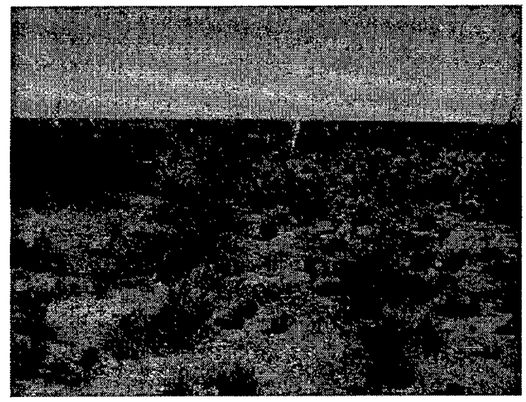


Figure 1. Picture of Fort Bliss Study Area.

The study area is located in the south-central New Mexico and western Texas. The bounding geographic coordinates are: 31° 48' N, 105° 32' W by 32° 42' N, 106° 35' W. Included in the Lower Sonoran Life Zone. In the Chihuahuan Desert, but Northern Portion may be in the "Desert-Grassland Transition Area" or "Desert Plains Grasslands" base upon reviews of logs and journals of early travelers and expeditions. Prior to cattle ranching in the late 19th century, the climax plant community was grasses. Today, these communities have been replace by several shrub species; primarily, *Prosopis glandulosa*, *Larrea tridentata*, *Flourensia cernua*, and *Artemisia filifolia*, which dominate the Tularosa Basin, Hueco Bolson and the alluvial fans entering the basins. Isolated areas of *Sporobolus* grassland can be found. The Otero Mesa and Hueco Mountains are dominated by the grassland communities of *Bouteloua eriopoda*, *B. curtipendula*, and *B. gracilis*. Encroachment of shrub species is evident.

The climate is characterized as a hot, dry desert with temperatures above 0 degrees C for all months. The mean annual temperatures range from 17.7 degrees C at El Paso, Texas to 14.8 degrees C at Jornada Experiment Range, New Mexico. Relative humidity of 26% during the day and 56 % at night. Half of the average annual rainfall occurs during the months of July through October where the average precipitation is variable throughout the year but rather uniform over the study area at 21.4 to 24.9 cm per year...coinciding with the major portion of the growing year. Summer precipitation is in the form of thunderstorms of high intensity while most of the winter precipitation is in the form of low intensity rains or occasional snows. There is an abundance of sunshine.

Fort Bliss region is in the Basin and Range physiographic province. Area consists of about equal proportions of basin and mountain range, including the Rio Grande Rift, a series of interconnected basins. The fault block mountains that trend north-south are the Franklin and Organ Mountains on the west. To the east are the Sacramento and Hueco Mountains. The mountains are separated by Hueco Bolson in the south and the Tularosa Basin in the North. The Hueco Bolson exhibits external drainage into the Rio Grande River whereas the Tularosa Basin exhibits internal drainage.

Franklin Mountains are composed of sedimentary and volcanic rocks – limestone with some sandstone and shale derivative in the northern and southern ends. Andesitic volcanic rocks are in the central portion. Granite underlies these mountains. The Organ Mountains are formed of intrusive granitic rock. Some sedimentary rock is found on the southern flanks and volcanic rock on the southwestern range. The Hueco Mountains are primarily limestone with some shale. There exists several granitic intrusions, Cerro Alto and Red Hill. He Otero Mesa are exclusively

sedimentary. The mesa is capped with limestone, with some sandstone and shale revealed in the escarpment. The Jarilla Mountains (unrelated to the eastern or western mountains) are of granitic intrusion. Sedimentary rock occurs in the northern end and in isolated linear outcrops.

Camp Williams, Utah

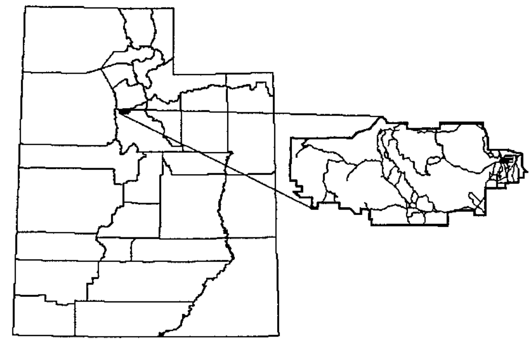


Figure 2. Location Map of Camp Williams Study Area.

Camp W.G. Williams occupies 25,000 acres in northcentral Utah, 26 miles south of Salt Lake City. It sits on the west slope of the Traverse Mountains. The Traverse Mountains, though very small (17 miles maximum length and 5.5 miles maximum width) maintain an importance out of proportion with their size because they separate the Great Basin geologic and physiographic province from the Western Rocky Mountains province and because of their unusual east-west orientation (Marsell, 1932). The Utah Lake drains into the Great Salt Lake through the Jordan River maintaining a wide flood plain over its entire course except along the narrow water gap called the Jordan Narrows where the river splits the Traverse Mountains into an eastern and western section (Marsell, 1932). The eastern border of Camp Williams includes the Jordan Narrows and its western border meets the Oquirrh Mountains. The camp is stratified by predominantly east-west drainages on the eastern half of the camp and north-south drainages on the western half of the camp revealing vegetation patterns that are strongly tied to slope and aspect. The vegetation is characterized by juniper woodland (*Juniperous osteosperma*), Gambel's oak (*Quercus gambelii*), and big sagebrush (*Artemisia tridentata*)/grass.

Elevations range from 4494 feet on the Jordan River to 7255 feet on Shep's Ridge in the Oquirrh Mountains. Slopes range from gentle, especially on the western portion of the installation, to very steep (up to 58 degrees), especially in Beef Hollow. There are seven basins or watersheds on Camp Williams; all of these have their upper reaches within the installation boundary.

Camp Williams has a characteristic continental climate of temperate deserts and semideserts with low precipitation and strong temperature differences between summer and winter (Bailey 1995). Most of the limited precipitation falls in winter and early spring and much of it comes as snow. This semiarid environment usually receives almost no precipitation in the summer. Precipitation is strongly related to elevation with average annual precipitation ranging from 250 mm (10 inches) at the lowest elevations to 500 mm (20 inches) at the highest. Average annual temperature in the vicinity of Camp Williams varies from 5-12^{0}C (40-55^{0}F) with a frost free period ranging from 60 to 180 days.

Major climatic influences on species establishment include hot summers with extended summer droughts and cold winter temperatures down to -25^{0}C (-13^{0}F). This climate favors cool season plant species which do most of their growth in the spring when moisture is available.

Camp Williams overlooks an urban complex of well over a million people. In addition to its relevance to the UTARNG training mission, Camp Williams represents an important block of wildland and biodiversity within a rapidly developing urban landscape.

Materials and Methods

Landsat MSS and TM

Both LANDSAT Multi-spectral Scanner (MSS) and Thematic Mapper (TM) data are available for each study site. MSS has approximately 80m spatial resolution while TM has 30m spatial resolution. The spectral resolution of MSS ranges from 0.5 – 1.1 µm within 4 bands while TM ranges from 0.45 – 1.25 µm within 6 bands of data. The data set ordered for Ft. Bliss consists of 104 wet and dry season MSS and TM images spanning 25 years of record. The data set ordered for Camp Williams consists of 43 wet and dry MSS and TM images also spanning 25 years. Of the 104 images for Ft. Bliss, approximately 35 images cannot be acquired digitally due to errors on original magnetic media. Likewise, of the 43 images ordered for Camp Williams, eight cannot be acquired digitally due to errors on the original magnetic media.

Kodak

Sensor Specs: The KODAK DCS 420 color infrared camera is being used to obtain data along degradation gradients and along ecotones at two elevations, 1460 feet giving 0.2m pixels and at 2200 feet giving 0.4m pixels with a 20mm lens. The spectral response is three bands in the blue, green and near-infrared which can be separated for analysis with image processing tools. The camera is a 1500 by 1000 pixel sensor.

Processing: Data from the KODAK camera in downloaded from the camera onto Adobe photoshop for examining the photographs. The photos are then imported into TNT MIPS image processing software. The bands are normalized for viewing to give the appearance of a color infrared photograph. Vignetting is removed with a detrending process in TNT MIPS. The original bands are used for initial classification attempts. We have been experimenting with convolution filtering, resampling, vegetation indices and different classification algorithms. Our initial attempts at classification during the last quarter of calendar year 1998 have shown that some classification success is resulting from the use of the three Kodak bands (RGB) along with a smoothing convolution filter, and the NDVI. In the future, we will be testing several additional convolution masks and additional vegetation indices.

CAMIS (Computerized Airborne Multicamera Imaging System)

SENSOR SPECIFICATIONS

Real-time GPS positioning
4 Cameras

Spectral Resolution:	Band 1 – 450nm (blue)
	Band 2 – 550nm (green)
	Band 3 – 650nm (red)
	Band 4 – 800nm (near infrared)
Band Width:	25nm
Frame Dimensions:	576 rows
	768 columns

Image File Format:	4-band, BSQ, zero header bytes
Geometric Correction:	none
Radiometric Correction:	
Band-to-band registration	
Cosine[4]	
Bi-directional reflectance factor	
Vignette correction	
Aircraft Altitude (AGL)	Nominal Spatial Resolution
6300 feet	1.0 meter
3200 feet	0.5 meter
1600 feet	0.25 meter

PROCESSING (All processing mentioned below was written in Matlab ".m" macro files. Each of these routines is to some degree automated and runs in batch mode.)

Each CAMIS frame is originally collected as two separate TIF files. The first is a three-band TIF that (normally) contains the near-infrared, red, and green bands, and the second TIF file contains the blue band. These files are grouped together under a common frame number. Thus the first step in processing the CAMIS frames is to combine the TIF pairs into a single band-sequential file.

The next step is band to band registration. The CAMIS optical head was built with the individual cameras in a linear array. The camera orientations were designed to be parallel. Although this means that the exact field of view for each camera will be different (especially at low altitudes), this allows for easier band to band registration. The reason for this is because with a parallel design the majority of band misregistration can be corrected by translation of each frame. Non parallel designs would require non-uniform scale changes across the image. When performing the band registration, all bands are registered to the blue, or first band. Tie points from the other three bands to the blue band are found through floating autocorrelation windows applied to edge maps from each of the bands. Normally, only one set of tie points is necessary for each flight line flown. New sets of tie points would be necessary if the distance between the aircraft and the ground changed appreciably during a flightline. Once a set of tie points is obtained, the green, red, and near-ir band are registered to the blue band using a first order conformal transformation, sometime known as a rotation-scale-translation (RST) transformation. Nearest neighbor pixel resampling is used in all cases.

Following band registration, each frame is cropped to remove edge pixels which may have bands that contain level zero DN's introduced by band registration. Normally, the cropping will be used to produce the largest rectangular frame possible. However, it is possible to produce non-rectangular cropped frames. The final step in processing CAMIS frames is radiometric normalization. Within frame radiometric effects, which are most notable when mosaicking sequential frames together, are a product of several phenomena. These include $\cos^3$ field darkening, vignetting, and bidirectional reflectance. The first two effects can be neutralized if the system is run through a rigorous calibration procedure. The last effect is a function of sun

and sensor geometry's, as well as covertype properties. However, given proper flight planning and imagery collection, it is possible to normalize within frame radiometric effects empirically. The technique used by TEC required the following collection parameters. First, during the collection of each flightline the solar conditions must not change appreciably. And second, enough frames must be collected in order to insure that there is no spatial bias for a certain land cover type to appear in any region of an image. For instance, on average over a flightline, the upper left portion of a frame should contain no more agriculture than the lower right. If this cannot be accomplished with a single flightline, multiple flightiness can be used if flown in the same direction in succession. The goal of this technique is to average many frames of CAMIS imagery containing the same covertype. If the system was perfect, and the terrain was Lambertian, the average of many frames of CAMIS imagery would be radiometrically flat. However, it turns out that the average is not radiometrically flat, but is usually a somewhat smooth continuous surface. The application of the inverse of this surface is then used to normalize for the above mentioned radiometric effects. Normally some type of mathematical function is fit to the inverse surface and then applied to each CAMIS frame. Both surface fitting and multiple polynomials have been used with approximately the same results. All CAMIS imagery collected for the SERDP project used surfaces.

Two additional types of radiometric normalization can be attempted but were not for the SERDP project. These are temporal and topographic normalization. Temporal normalization may be necessary if the atmosphere changes during imagery collection. This normally would need to be considered for mosaics created from many flightiness. Topographic normalization can be done to compensate for slope-aspect effects. This requires the use of a high resolution digital terrain model. This is normally necessary in areas of substantial relief (such as Camp Williams) but is of little use in flat areas (such as Fort Bliss).

IRS

The Indian Remote Sensing 5m fuse blend data is being used to improve existing vegetation maps for the military reservation chosen for study. These data include a 5m panchromatic band colorized with the TM RGB data. Classification efforts have been started using this data, but accuracy has yet to be tested.

Figure 3. Sample IRS image shows one overflight area at Camp Williams.

DOQs

Digital Orthophotoquads are generated from black and white aerial photography stereo pairs with an on ground resolution of 1 meter. These data are planimetrically and geometrically corrected to 1:12,000 scale. DOQ tiles correspond to quarter quadrangle sections of the standard USGS 7.5 minute quadrangle sheets. These data are available for Camp W. G. Williams, and Fort Bliss.

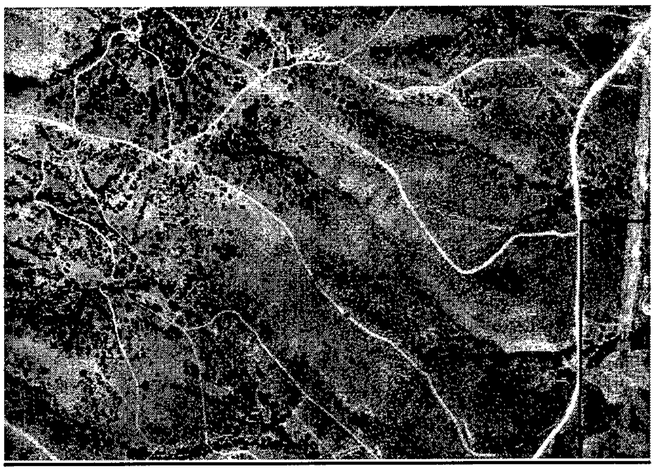


Figure 4. Sample DOQ shows aerial survey target location for an overflight at Camp Williams.

IFSAR (Interferometric Synthetic Aperture Radar)

IFSAR is a dual antennae active sensor that pulses the topographic surface. The resulting processing of signals provides a relatively high resolution digital elevation model (DEM). TEC, USU, and CW worked with Intermap for STARS-3i (IFSAR) acquisition over the Camp Williams study sites; the researchers provided maps and coordinates to help Intermap prepare the costs and schedules. The purchase order was processed through USU and the researchers are waiting to hear back from Intermap. The POC at Intermap is Mr. Marc Wride.

Field Transects and Data Collection

The phytosociological and terrain data were collected at 10 sites on Fort Bliss and 3 sites on Camp Williams. Field vegetation sampling transects were placed on opposite sides of ecotone boundaries or along degradation gradients. Sample locations were randomly selected within homogenous plant communities on each side of each ecotone and at specified locations along degradation gradients. Three 50m line transects were placed along random vectors radiating outward from a randomly located central point within each plant community. All transects were constrained by assuring that they fell within the represented plant community. There were a total of 69 transects sampled during the summer of 1998. Line intercept rules were written for the vegetation sampled and the resulting data expressed in terms of percent plant cover. (See Appendix 2 for transect data sheets)

Fort Bliss: Location/Description of Ecotone/Degradation Sites:

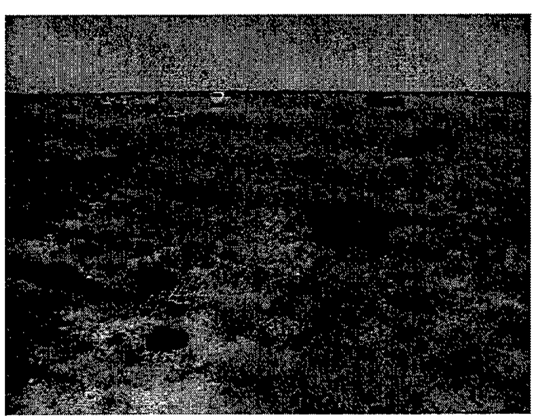
Sites 1 through 3 represent ecotone gradients. Sites 4 through 8 represent degradation gradients. Sites #2 and #6 are on very close to each other, and therefore only one coordinate is provided for both. Sites #7 and #8 are also very close to each other, and are only represented by one locator on the map, even though separate GPS coordinates are provided for each. Sites #9 and #10 represent areas where recent wildfires have occurred.

Site #1: E: 395040 N: 3556215

Description: Subtle ecotonal gradient between creosote (*Larrea tridentata*) and Sand Sagebrush (*Artemisia filifolia*) and grading into mesquite (*Prosopis glandulosa*) and associated shrubs. Located on the SE side of straight road running NE away from McGregor Range Camp and towards Otero Mesa. For some reason, this road does not appear in the vector map, although it appeared to be a well maintained primary road? Transect can be placed parallel to the road on the SE side of the road.

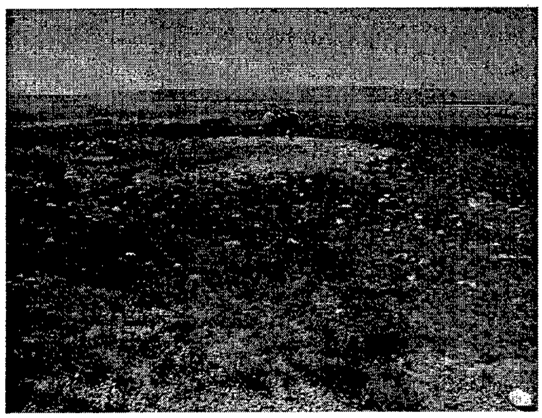
Sites #2 and #6: E:411889 N:3561764

Description: Site #2 is a Gramma (*Bouteloua*)-Tobosa (*Hilaria mutica*) ecotone with Tobosa located in a drainage depression and Gramma existing up slope in both directions. Site #6 is the Campbell Springs tank maneuver site. I tank maneuver site (our site #6) is found just to the north of the swale.



Site #3: E:368275 N:3550478

Description: Echo Site/3 Way ecotone between Mesquite Dunes, Three-*awn (Aristida purpurea)* grassland with numerous weedy species and creosote bush. Since this site represents an ecotone between 3 different communities, we want to lay out our panels in a triangular fashion with each corner residing in a different community. Flight lines will then traverse each side of the triangle and image the ecotone between each of the 3 communities. This site is where we actually measured a field transect.



Site #4: E:437612 N:3583267

Description: Toy Tanks piosphere with cattle grazing as primary impact.. The basic degradation gradient runs east and west from the Toy tanks watering point with one transect location to the south. The idea is to move outward from the most impacted area to the less impacted areas several miles from the watering points. This is a degradation gradient impacted by livestock grazing.

Site #5: E:376202 N:3559098

Description: Crossroads in mesquite dune maneuver or marshaling area. It is an area where several roads meet. Large areas of bare ground are found between the large dunes. We are beginning to examine the size and orientation of the dunes in relation to the impact.

Site #7: E:412087 N:3591507
Description: Tank maneuver site4

Site #8: E:412294 N:3591846

Description: Tank maneuver site5

Site #9: Sites #9 and #10 are both fire plots. During 1998 only Site #10 was field sampled.

Site #10: This site includes a recent burn in a Creosote Bush/Tar Bush (*Flourensia ceruna*) community. There are scattered patches of Tobosa Grass throughout.

<u>**Camp Williams: Location/Description of Ecotone/Degradation Sites**</u>

Site #1:

Description: 200 series firing point. Includes heavy vehicle traffic from artillery training and associated foot traffic from soldiers. Vegetation dominated by shrubs and grasses. Transect crosses military impact "piosphere" and represents a degradation gradient.

Site #2:

Description: Region V NCO training area is a popular bivouac site. Includes heavy foot traffic and camping. Area dominated by Juniper (*Juniperus osteosperma*) woodlands with Sagebrush (Artemisia tridentata) and other shrubs and grasses present. This site represents a degradation gradient.

Site #3:

Description: Tickville drainage site. Little military training occurs here. Area has been burned prior to sampling. Site is dominated by Oakbrush (*Quercus gambelii*) and Juniper (Juniperus osteosperma) both in burned and unburned states. This site contains the most topographic relief of all three sites and represents an ecotonal gradient.

Discussion/Accomplishments

Retrospective Study

Image Analysis

In collaboration with personnel at Ft. Bliss and Camp Williams, the researchers have completed the image selection for the historic remote sensing data. The data set ordered for Ft. Bliss consists of 104 wet and dry season MSS and TM images spanning 25 years of record. The data set ordered for Camp Williams consists of 43 wet and dry MSS and TM images also spanning 25 years. Of the 104 images for Ft. Bliss, approximately 35 images cannot be acquired digitally due to errors on original magnetic media. Likewise, of the 43 images ordered for Camp Williams, eight cannot be acquired digitally due to errors on the original magnetic media. We will evaluate the current imagery and determine if the loss of data will impact the study.

We have developed algorithms for improved and more efficient image processing of large (50 - 100 image) contemporary satellite datasets as a result of collaborative research between ORNL, EPA, and USU. R.A. Washington-Allen is working with Drs. Ramsey, West, Hunsaker and Paul Schwartz on an EPA Office of Research and Development National Center for Environmental Quality (NCEQA) funded research project to develop remote sensing based ecological indicators of ecological integrity. Other aspects of the algorithms developed , specifically regression analysis, have come through collaboration of the SERDP team with USU's National Environmental Database (NED) project.

Algorithm development has focused on procedures to 1) standardize heterogeneous satellite platforms by conversion of digital numbers to at-sensor reflectance; 2) perform relative atmospheric correction, 3) substitute signals of one sensor for another, and 4) detect the response of ecological indices in concentration areas. The algorithm developed for relative atmospheric correction is an innovation in the field where we have automated a process which was highly labor intensive.

The atmospheric correction algorithm work has focused on incorporating the Kauth-Thomas Tasseled Cap Transformation's soil brightness index (SBI). The SBI is used to identify surface features which do not change over time. Also, the researchers have added the flexibility to choose the standard deviation level to threshold the SBI and choose a sample of a minimum of six points for the regression. In addition, R.A. Washington-Allen, Tom Van Niel, Brian Beach, and Paul Schwartz worked together on developing software to atmospherically correct single-scene multitemporal imagery. In collaboration with Kimberley Patraw Van Niel of the NED program, the researchers are in the process of adding the capability to perform regression formula determination. These image processing techniques and indicator developments directly benefit the retrospective study component of this project by being used in the preparation of the SERDP datasets.

The algorithm developed for sensor substitution calibrates different sensors to a common standard signal response. Where direct substitution is not possible researchers have to determine how Landsat Thematic Mapper (TM) can simulate Landsat Multispectral Scanner (MSS) sensors or MSS can simulate TM. This problem also extends to the other sensors we are using such as CAMIS, Hydice, Atlas, etc.. The basis for development of a global formula for standardization between sensors requires sensors to have conditions where the only difference between them is

sensor response, thus images must have clear atmospheric conditions at the same targets. If this is the case, simulations can be calculated.

MSS bands 1, 2 and 4 can be adequately simulated using TM bands 2, 3 and 4 and MSS band 3 can be simulated using a combination of TM bands 3 and 4. If direct substitution is used the simulation would use TM bands 2, 3 and 4 to predict MSS bands 1, 2 and 4 using a linear regression. Using a combination of TM bands 3 and 4 to simulate MSS band 3 is a three-variable multiple regression problem where Y' (MSS3) is predicted from X1(TM3) and X2(TM4) and the formula is:

$$Y' = a + b1TM3 + b2TM4 \quad (1)$$

$$Y = a + b1TM3 + b2TM4 + e \quad (2)$$

where Y is the observed MSS values and Y' is the predicted.

Alternatively, all bands of a number of sensors can be used to predict each band of another sensor, i.e.,

$$Y' = a + b1X1 + b2X2 + bnXn$$

We have also begun optimization studies of vegetation indices and soil, i.e., relationship of site water balance model's (SWB) soil moisture derivatives to the soil-adjusted vegetation index (SAVI). A SWB model is a hydrological model which accounts for water budgets in different parts of a landscape or ecosystem, they are also called hydrological models in general, but specifically SWB models are a way at getting at water availability in a landscape's soils. For our study this has two benefits, 1) we can spatially determine sites most likely to benefit from moisture inputs and 2) we can use soil moisture levels as a weighting process for remotely-sensed vegetation index response. The model can also be used as an input to examine changes in plant species distribution with changing moisture conditions, a common phenomena for semi-arid and arid systems. A more detailed discussion of SWB and biophysical modeling is given below.

Biophysical Modeling

The biophysical modeling exercise aims at generating a time series of site water balance (SWB) maps for the study areas of Ft. Bliss and Camp Williams. In this model the SWB is driven by basic climatic pedological processes. High-resolution maps of these biophysical parameters have to be generated in order to enable the SWB calculations. The model assumes that the soil moisture is primarily influenced by a balance of gain (precipitation) and loss (evapotranspiration) of water over the location-specific soil bucket. Lateral sub-surface movements of soil moisture are neglected. Potential evapotranspiration is driven primarily by solar and thermal energy. Once the basic maps of temperature, radiation budget and precipitation and potential evapotranspiration are generated, the site water balance can be integrated over the bucket size. At no time can the amount of stored water exceed the local bucket size. Usually, the integration starts at the beginning of a "water year",

i.e. in fall after the end of a potential drought season. For the SERDP-purpose, the integration of the water balance is halted at the date the images have been taken. Following is a description of the methods to generate the respective biophysical parameters.

Digital Elevation Models

For the biophysical mapping exercise we chose the 7.5' USGS digital elevation model as a parsimonious compromise between spatial accuracy and computational efficiency. For each study site, the USGS DEM-quads were merged and cleaned for errors at the margins.

Precipitation and Temperature

Daily maps of precipitation and minimum/maximum temperature are provided by the Utah Climate Center (UCC). The maps were generated by spatially interpolating daily meteorological values as measured at NWS and SnoTel climate stations. The spatial interpolation was performed based on minimum curvature interpolations of stations values that were transformed as if the stations were situated at 0 m.a.s.l. Standard lapse-rates were applied to transform the stations measurements to sea level. The data are provided in 500m spatial resolution. This resolution is high enough for precipitation (Daly et al., 1994), but does not satisfy the needs for min/max. temperature as required in our modeling exercise. Thus, we had to re-project the temperature maps to sea level, spatially interpolate the sea-level temperature surface by inverse-distance weighted interpolation to the 30m pixel-size of the DEM, and re-calculate the 30m temperatures based on the same standard lapse-rates.

Solar Radiation

Direct insolation is calculated using the SHORTWAVE model (Kumar et al., 1997). The model is very similar to the SOLARFLUX model (Dubayah and Rich, 1995; Rich et al., 1995), but it is computationally more parsimonious, and is very easy to adjust to our needs. Since we need to simulate specific rather than long-term normal radiation budgets, we added daily atmospheric transmittance values to the model as measured by the respective stations of the SAMSON network. Such measurements are available from 1961 to 1990. Additionally, we incorporated the increase in transmittance with increasing elevation. We adopted the method of Thornton et al., (1997) by applying an increase of the transmittance by 0.0008 per 100m of elevation. However, we plan to test this value with the SAMSON data sat. For the years after 1990, the method of Bristow and Campell (1984) is used to predict daily atmospheric transmittance from the diurnal temperature range (see eqn. 1).

(1) $$Tr = A \cdot \left[1 - \exp\left(-B \Delta T^{C}\right)\right]$$

where Tr = atmospheric transmittance; A,B,C = empiric coefficients; ΔT = diurnal temperature range (as calculated in eqn. 2).

(2) $$\Delta T(J) = T_{max}(J) - \left(T_{min}(J) + T_{min}(J+1)\right)/\ 2$$

where *Tmax* = daily maximum temperature; *Tmin* = daily minimum temperature; *J* = Julian Day. No increase in transmittance is simulated here, since the diurnal temperature range in higher elevations accounts for this difference already (Thornton et al., 1997).

Diffuse solar radiation is calculated with the DIFFUSE model, a procedure described in (Kumar et al., 1997). Direct and diffuse radiation are summed to derive the radiation budget.

Potential Evapotranspiration

Potential evapotranspiration is calculated for the study area using the empirical equation of Jensen and Haise (1963), which was derived from data of the arid western United States (eqn.3). This method is based on monthly mean values for daily solar radiation and temperature, but can be applied to daily values as well.

(3) $$ETp = 0.245 \times 10^{-4} \times Rs \times (0.025 \times Ta + 0.08)$$

where: *ETp* = mean daily potential evapotranspiration (mm/day), *Rs* = daily total solar radiation (kJ/m^2/day), *Ta* = mean daily air temperature (°C). Comparative calculations based on the Solar Thermal Unit method (Caprio, 1974) and the Turc method (Turc, 1963), both based on the same independent parameters, revealed very similar results. The empirical formula of Jensen & Haise was selected because it was especially designed for the arid Western States, and revealed the most likely values.

Bucket Size

Bucket size as defined in this model is a simplified representation of actual water storage capacity of soil. Two approaches are previewed to generate maps of the bucket size for the study areas. They are based on the availability information on the soils. If such information allows for calculation of the water storage capacity (mm/m soil depth), and the soil depth (m) directly, then this method is preferred. Otherwise, an expert-system approach is employed to generate maps of the bucket size as described below.

Topographic position, necessary to classify soil properties over large areas, is calculated using a hierarchically nested approach. Using circular moving-windows with a radius ranging from 60m up to 3000m on the 30m DEMs, the difference between mean window elevation and the center cell of the window is calculated. The resulting maps are interpreted as relative exposure at different spatial scales. A hierarchical integration into a single map is achieved starting with the standardized exposure values of the largest window, and adding standardized values from smaller windows where these smaller scale values exceed values of the larger scale map. The resulting map is classified into 4 principal topographic classes: ridge, slope, toe slope and bottom. These topographic characteristics are then used, together with an ecological classification of the surface geology, to define coarse fragment content, soil depth, soil texture, and specific soil moisture holding capacity (see Roberts

et al., 1993). The following equation (eqn.4) is used to calculate the soil bucket size thereof:

(4) $$Bucket = D \times SSMC \times \left(1 - \left(CFC/\ 100\right)\right)$$

where: D = soil depth (meter), $SSMC$ = specific soil moisture holding capacity (mm/m) and CFC = coarse fragment content (%). $SSMC$ represents the difference between field capacity and permanent wilting point of specific soil textures, reflecting differences in pore volume and pore diameter distributions by texture.

Site Water Balance

Bucket size, potential evapotranspiration and precipitation are then combined to calculate the spatially-explicit site water balance similar to the approach first employed by Grier and Running (1977). Beginning with the first month in fall when precipitation exceeds potential evapotranspiration (after a possible drought period), the difference between precipitation and potential evapotranspiration is summed for 12 months. The running sum is never allowed to exceed the bucket size, and water in excess of the bucket size is presumed to run off. When potential evapotranspiration begins to exceed precipitation the difference is subtracted from water in the bucket, often achieving significant negative values over the course of a year. Site water balance is an estimate of the water available to plants during the year, and integrates both climatic and soil parameters. The method differs from Grier and Running (1977) in the determination of the appropriate water year, and in not assuming that soils begin the water year with full recharge.

Ecotone Study

Discussions between the SERDP researchers and the land managers intensified as plans for study site selection, field work, image acquisition and over-flights were scheduled and conducted during the year. The proposed research (and associated field work) was discussed and meetings coordinated between each of the SERDP participants as well as the land managers on the respective research sites (the primary POC for Fort Bliss and similarly Camp Williams have been the facility's Directorate of the Environment). Several trips were made to Fort Bliss by the various researchers to acquaint themselves with the people and the terrain, select the study sites, prepare the sites for aerial imagery acquisition (e.g., ground markers and GPS coordinates), and collect ground information (e.g., vegetation transects). The researchers examined a number of field sites and, by consensus, selected 10 sites for data acquisition using both UNR's Kodak digital camera and TEC's CAMIS multispectral sensor system. Similarly, the researchers visited Camp Williams (CW) to: select the study sites, prepare the sites for aerial acquisition, and collect ground data. The researchers examined a number of sites at Camp Williams and, by consensus, selected 3 for data acquisition. Close cooperation between the project scientists and the Fort Bliss and Camp Williams environmental scientists has proved invaluable. Environmental Scientists at Fort Bliss and Camp Williams has provided significant benefits in terms of both materials (e.g., vehicles, manpower) and knowledge of the terrain/ecosystem.

At the onset of the project, UNR, UIUC and TEC found it necessary to review in-house capabilities. The review was necessary to determined those capabilities (e.g., landscape licenses,

workstations, data storage) necessary to conduct the research and those capabilities available to the researchers; where applicable, the facilities were modified or updated.

UNR and TEC initiated the procurement of high-resolution imaging systems, Kodak and CAMIS respectively. Upon receipt of the imaging systems, UNR and TEC fabricated aircraft mounts for the sensors to fit in the belly of an aircraft. Efforts to coordinate the flights of both TEC's CAMIS system and UNR's Kodak digital camera began with an initial look into flight services for each study site. There was limited success in locating a flight services company near Fort Bliss. This coupled with the difficulty of acquiring an aircraft with the proper camera hatch at the times required has increased the difficulty of obtaining the aerial data. The decision was made to select a single company to fly both sights. Comstock Air out of California was chosen based upon previous success with UNR. Both of the high-resolution video sensors were flown from a Cessna 206 single engine, high-wing aircraft with a factory mounted 18 inch camera hatch.

A significant effort was expended in coordinating and ultimately executing a simultaneous collection of Kodak and CAMIS imagery. Each mission required compatible schedules between the UNR, TEC, Comstock Air, and Range Control. But compatible schedules did not guarantee success. One constraint that proved to be a problem time and time again was the weather (an unexpected problem since the sites are deserts). For example, the three sites at Camp Williams were scheduled to be flown by both the Kodak digital camera and CAMIS system in June. Plans were made and the aircraft and people were scheduled. But due to poor weather conditions, the flights were canceled and rescheduled for July. July was finally when the first set of flights was conducted over Camp Williams. Later in the year, a second set of flights was scheduled for Camp Williams. Once again, plans were made and the aircraft and people scheduled. TEC had gone so far as to send people to Utah. But once again, poor weather conditions forced cancellation of the flight. Poor weather conditions has so far precluded a second overflight of Camp Williams.

Despite the obstacles to planned overflights, a significant amount of imagery has been acquired. Fort Bliss was flown by both sensors twice. Camp Williams has been flown once. Seven of the 10 sites at Fort Bliss were flown at varying resolutions in both June and August. The image resolutions included 0.2 and 0.4 meters for the Kodak and 0.25, 0.5, and 1.0 meters for the CAMIS. The June set for Fort Bliss captured dry season conditions, whereas the August set captured wet season. The newly acquired CAMIS and Kodak data was prepared and analyzed, including radiometric correction (discussed earlier) and mosaicking. Optimum procedures for doing both mosaicking and correction are being further investigated and modified as we gain familiarity with the new sensors. The CAMIS imagery was radiometrically corrected by TEC and has been distributed to all project researchers. The Kodak imagery was similarly distributed to each of the researchers.

Methods have been developed by TEC to radiometrically correct and mosaic the CAMIS high resolution multispectral images. Methods are now being developed to automate handling the large number of CAMIS images. This will speed up processing and simplify the application of the data. UNR is working on similar methods for the Kodak high resolution imagery. Ft. Bliss Digital Orthophoto Quads (DOQ's) were acquired from the Fort Bliss Department of the Environment (DOE) to be used for georeferencing the collection of aircraft video imagery.

Various methodologies for data analysis, handling and storage were considered. The researchers are testing various image processing methods/techniques for vegetation classification on the IRS, Landsat, and other sensor images. Similarly, the researchers have begun work on developing procedures for analyzing ecotones using CAMIS and the Kodak videography. The following paper was prepared by Dr. Tueller and presented at the The Tenth Wildland Shrub Symposium at Snow College, Ephriam, UTAH, August 12-14, 1998. (The proceedings will be published in early 1999.) Dr. Tueller will revise the paper as the researchers critique these techniques over the course of the project.

Tueller, P.T. 1998. Approaches to mapping ecotone boundaries using emerging remote sensing technology.

The researchers have imported a number of images and image types into their image processing systems for analysis, including Kodak, CAMIS, IRS, and Landsat TM imagery. CAMIS and Kodak images for Ft. Bliss and Camp Williams were downloaded to CD ROM. Copies of these data were distributed to the consortium of researchers. Similarly, all sixteen IRS 5m quads were distributed. The CAMIS and Kodak imagery from later flights were duped on CD-ROMs and have been distributed to all researchers working on the ecotone study. The IFSAR overflight at Camp Williams has not yet been flown but a purchase order has been prepared and scheduling is underway.

Internet 'ftp' sites have been established at several of the research facilities to ease movement of imagery, data, and research results between the researchers. A significant amount of information has transferred this way in addition to the trading of data on CDs. In addition, internet web-sites are being developed by several of the research facilities to garner interest and promote technical exchanges with other scientist doing complimentary research.

Mosaics of the imagery (e.g., CAMIS, EOSAT IRS 5m pan sharpened imagery) were generated. The creation of these mosaics involved a series of steps including, but not limited to, radiometric correction and georeferencing. DOQ's were used, in part, for the arduous task of georeferencing the larger scale images (e.g., CAMIS) and correlating image areas with areas covered by vegetation transects....this process continues. UIUC is georeferencing the Fort Bliss data while USU completes the same for Camp Williams. Hard copy image mosaics of transects were created, taken to the field, and used during the field verification efforts. The hard copies of the field verification photos were provided to Ft. Bliss. GIS data have been compiled from the environmental office at Ft. Bliss and currently resides on-line with project researchers. GIS data of Camp Williams has been updated and cleaned.

In addition to establishing vegetation transects at both study sites (Appendix 2) field verification of identifiable plant species was also accomplished at Ft. Bliss on four study sites for 7 ecotones and one piosphere. Similar field work is underway at Camp Williams. These field determinations were designed to check species identification potential at the various scales for the CAMIS imagery (1.0, 0.5 and 0.25m) and the KODAK imagery (0.2 and 0.4m) as compared to the transect/study sites. On occasion, field work was dedicate to the preparation of sites for aerial acquisition.

Procedures are being developed for classifying plant associations across ecotones, and for classifying individual species, species guilds and surface soil characteristics. A high resolution image data base is being developed to analyze plant community species distributions by distance from the watering tank. Studies are being conducted to use EOSAT IRS 5m pan sharpened imagery for the many watering tanks on Otero Mesa. Dallas Bash, Fort Bliss DOE, has volunteered 'arc coverage' data from BLM of all watering tanks on the Mesa. The researchers have begun to evaluate heterogeneity and diversity measures as a function of distance from the watering tanks. This will provide some early insight into the utility of these images to assess disturbance.

As a part of our efforts to classify large scale videography we are identifying and quantifying spectral signatures for individual species and species groups. Cooperation has been established with scientists on a new SERDP initiative just about to start. This projects is one with Bechtel Nevada. Dr. W. Kent Ostler is the principal investigator. They are working with SPSS and a software program titled Sigma Scan Pro 4.0 which will be used to examine the spectral characteristics of individual species. We will be comparing this software with the software that we are using, for example TNT MIPS.

A field sampling protocol was developed by consensus of the researchers and has been described earlier in the report (see Appendix 2). Transect sampling was conducted at both study sites by UNR, UIUC, CERL. Field transects for species and surface soil characteristic, using procedures previously described, were completed at Ft. Bliss for 7 sites. Detailed field verification of identifiable plant species was also accomplished at Ft. Bliss on four study sites for 7 ecotones and one piosphere. Similar field work was accomplished on Camp Williams. On occasion, field work was dedicated to the preparation of sites for aerial acquisition. Also, field work was designed to check the 1m, 0.5m, and 0.25m CAMIS imagery against several transect/study sites. Likewise field checks were made to document species identification on the 0.2m and 0.4m pixel KODAK images. These are then used to check classification accuracy on the large scale video images.

UIUC hired a full-time research data analyst to help prepare the image data sets for Ft. Bliss. Tari Weicherding, has a degree in Ecology, Ethnology, and Evolution from UIUC. This is leveraged funds from outside of SERDP. In addition, UIUC hired an undergraduate student in geography, Michelle Suarez, to work on data processing.

Original bands of the KODAK RGB images are being used for initial species or species group classification attempts. We have been experimenting with convolution filtering, resampling, vegetation indices and different classification algorithms. Our initial attempts at classification during the last quarter of calendar year 1998 have shown that some classification success is resulting from the use of the three Kodak bands (RGB) along with a smoothing median convolution filter and the NDVI. In future we will be testing several additional convolution masks, additional vegetation indices and classification algorithms..

Researchers are discussing the question of upscaling from the large scale videography to the smaller scale imagery such as the IRS 5m data. This will be a strong effort during the second year of the project. Newly developed vegetation maps of the study areas are being or will be examined in relation to the ease of first identifying the ecotone and secondly defining the exact location of the boundary with higher accuracy. Emphasis will be given to measuring species

differences across the ecotones and determining their exact location on the landscape. This higher accuracy of mapping will improve the ability of scientists and managers to determine the movement of change in the ecotones and thus improve the ability to measure successional changes within the landscapes. Monitoring will be improved and management efforts will be more timely and accurate.

Concerns

One concern is that the IKONOS sensor has not yet been launched. Also, weather conditions proved to be contentions on several occasions forcing either delays or cancellations of overflights. Bad weather forced a several week delay in flying the sensors over Camp Williams early in the year; then, the second scheduled aerial acquisition was called off; the aircraft reservation was cancelled; and, the researchers who had traveled to Camp Williams were recalled. This has forced a rescheduling of the flight. Three of the four flights have been completed. Drought conditions (even for a southwestern desert) remain at Fort Bliss. Field work has become a concern at times.

Acquiring nested very high resolution imagery proved difficult to obtain at each and every study site. With greater investment in the upcoming years to ground preparation, the acquisition of nested imagery should no longer prove elusive.

Although the researchers have acquired a significant portion of the available commercial data, a portion of the ordered data has yet to be delivered. A late revelation by EROS Data Center revealed that a large quantity of ordered data was in hardcopy only. The digital files remain elusive. The delivery of the remaining image resources is presently on-going but not complete.

Planned

During FY99, vegetation maps will be completed for the original two study sites: Camp Williams, Utah, and Fort Bliss, Texas. The maps will be interpreted from IRS 5-meter imagery (one of the newer remote sensing systems). These maps will be tested for accuracy and compared to previous maps prepared from the older, more contemporary systems, the Landsat MSS and/or TM sensors. Procedures will be developed for interpreting and then incorporating the data from other emerging sensors (e.g., CAMIS, Kodak) into the project hierarchical database. The database will be populated with data from varying scales of resolution. Given the newly populated database, work will commence on developing procedures for relating the various spatial and spectral characteristics of the remotely sensed data and the composition of vegetation and soil attributes with regards to degradation gradients. This will be done by relating spectral characteristics of the imagery to individual species or species groups based on field examination. Plus, work will commence on examining the successional differences across ecotones again using the spectral characteristics of remotely sensed data at the various scales. Procedures will be developed for upscaling from large to small scales. With some early success, procedures will be considered for placing such information into the Ecological Dynamic Simulation (EDYS) model. Using the experience gained at the original two study sites, the researchers will start at a third study site. Work at the third site will include, but not be limited to, the acquisition of imagery and data over the site, and, field work on the site itself. Presently, a consensus has developed to use 29 Palms, CA, as the third site, given the amount of available data and the on-going research at the facility (both SERDP and non-SERDP funded projects).

Also during FY99, the researchers will continue development of algorithms for improved and more efficient image processing of large contemporary satellite databases (50 - 100 images). This will include liaison with others working in the field to solve the problems of image mosaicking, e.g., bi-directional reflectance correction. Optimization studies of vegetation and soil indices will be conducted by the researchers, including but not limited to the relationship of a site's water balance (SWB) model's soil moisture derivative to the soil-adjusted vegetation index (SAVI). A part of this is the development of spatial interpolation methods to account for sparse climatic data. The SWB models, or hydrologic models, determine water availability in the landscape and thus provide the researchers information on soil moisture availability. Given soil moisture levels, the researchers can determine where spatially in the landscape the moisture will be most accessible. This in turn provides a weighting process for the remotely-sensed vegetation index response. During the fiscal year, IFSAR ground calibration will be conducted and relationships will be established to SAVI and SSI. Finally, spatial accuracy/uncertainty analysis will be undertaken to include the selection of sites, sensors, and techniques.

The diversity of data resources, imagery types, hardware and software systems, and, the researchers involved provide a unique challenge in information exchange. To facilitate data exchange, internet 'ftp' sites will be established at each of the research facilities and potentially the study sites. These 'ftp' sites will allow the researchers to download data from one anothers databases. Furthermore, internet 'web-sites' will be created to garner interest and more importantly promote technical exchanges with others outside of the project. The internet

web-sites at several of the researchers facilities will be linked to one another, thus providing a cohesiveness to the project and the research partners.

The CS-1098 project will leverage a significant number of other programs and research efforts. The Utah Army National Guard (UTARNG) and the National Guard Bureau (NGB) have been working with, and will continue working with, USU and Camp Williams on database development, update, and analysis, as well as map composition, image analysis, and GIS development. NGB will also task the National Resource Conservation Service (NRCS) and the Waterways Experiment Station (WES) to conduct soil surveys and wetland inventories, respectively, on Camp Williams. Fort Bliss and CERL are coordinating research in Land Cover/Condition Trends and "Spectral Demixing for Sub-Pixel Quantification of Land Cover." The EPA Office of Research and Development (ORD) and the National Center for Environmental Research and Quality Assurance (NCERQA) are working with ORNL on "Remotely-sensed indicators of rangeland health over large areas." TEC is working with various agencies such as the U.S. Military Academy, University of Reading, Virginia Institute of Marine Science, and the Naval Research Lab (NRL) on complimentary research, including: heuristic rules in image exploitation, spatial data variation, and predictive terrain modeling. All of these programs have and will continue to make available the data, algorithms, hardware and other resources necessary to conduct the SERDP research. For example, the data resources complimenting the SERDP effort include: floristic and faunal surveys, soil and vegetation maps, fire history and fuel inventories, LCTA monitoring data, range utilization studies, and plant community surveys.

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Appendices

Appendix 1 – Retrospective Analysis Example

Date of Report: October 20, 1998
EPA Grant Number: GAD # R826112
Title: Characterization of the Ecological Integrity of Commercially Grazed Rangelands Using Remote Sensing-based Ecological Indicators
Investigators: Neil E. West[1], Robert A. Washington-Allen[1], and R. Douglas Ramsey[2]
Institution: 1. Department of Rangeland Resources, and 2. Department of Geography and Earth Resources, Utah State University, Logan, UT 84322.
Research Category: Ecological Indicators
Project Period: Nov 1998 - Nov 1999 (2 years)

Objective of Research:

We are using 27 years of wet and dry season Landsat satellite imagery from (1972 - 1998); a GIS database of site biological, physical, and administrative characteristics and analysis tools; historical and current ranch management records; and a multiple-time by nested multiple-scale experimental design to establish causal links between possible threshold response of ecological indicators diagnostic of land degradation and human management interventions in order to assess the ecological integrity of ecosystems within a semi-arid landscape subject to commercial livestock grazing.

Progress Summary/Accomplishments:

The study site selected for this research is the Deseret Land and Livestock Ranch located in the northeast corner of the Utah panhandle. The first stage of our project has been GIS and remote sensing data acquisition and development (Table 1). Extension activities with Deseret's land managers has yielded eighteen years of livestock (1980 - 1997) and sixteen years of wild ungulate (1982 - 1997) management data (Fig. 1 and 2). Twenty-six years of wet and dry season imagery (49 scenes) and two years of annual imagery (1985 and 1986, ~ 9 scenes/year) are being image-to-image rectified. Image normalization of the data set is occurring via transformation to exo-atmospheric reflectance values and use of an empirical radiometric normalization technique to relatively atmospherically-correct imagery to a reference image. Landsat MSS data collection ceased after 1992, thus wet and dry season Landsat Thematic Mapper (TM) imagery from 1986 to 1997 (Table 1.) was acquired and multiple regression techniques are being used to allow TM sensor response to simulate MSS sensors. The image processing procedures used in this study are labor intensive, but we are automating this process in collaboration with scientists from a DoD Strategic Environmental Research and Development Program (SERDP) conservation project that is concerned with developing remote sensing-based environmental monitoring protocols for military bases.

In preliminary studies, seasonal images from 1972 to 1997 were converted to the soil-adjusted vegetation index (SAVI) images and analyzed. In general, wet (Fig. 3A) and dry (Fig. 3B) season mean/variance plots clearly discriminated two domains of attraction with the characteristics of high mean/low variance in the 1970's and low mean/high-low variance in the 1980's and 1990's (Fig. 3). The two domains correspond to wet and drought years as determined by the Palmer Drought Severity Index for this period. The wet and dry season mean/variance plots have aperiodic temporal trajectories with aperiodic orbits within the two domains. This identifies the two domains as "strange attractors" [rather than fixed point (e.g., the diverse flight trajectories of flies to honey) or limit cycle (e.g., a clock cycle) attractors] and is indicative of a chaotic system (Casti 1995) . During the dry season, the threshold or shift between the two domains occurred in 1981. During the wet season, the threshold between the two domains occurred in 1978 (wet to dry period), 1980 (dry to wet period), and 1981(wet to dry period). After 1981, Deseret's landscape fails to recover to conditions in the 1970's.

Three hypotheses were tested at the landscape and administrative scales: 1) at the landscape scale, the El Niño wet year of 1983-84 would be manifest when compared to mean conditions; 2) The period from 1972 to 1983 would have lower vegetational cover than the period 1984 to 1997 because of better ranch management; and at the administrative scale, 3) vegetation cover within Bureau of Land Management (BLM) islands would not differ from that of the paddocks they were within because Deseret Land and Livestock does not separately manage on the basis of land ownership. We found that 1) the El Niño wet year of 1983-84 allowed most of the landscape to recover from an apparent drought in 1982, except for riparian areas which had lower than mean vegetational cover 2) Contrary to our hypothesis, the period from 1972 to 1983 had higher vegetation cover than the period 1984 to 1997. This may be due to a combination of drought and management interventions (e.g., haying operations); and 3) vegetation cover between BLM islands and the paddocks which contained them did not differ as expected (Fig. 4).

Both one year-lagged wet and dry season vegetation cover are related to livestock stocking rate of the previous year (Fig. 5). Stocking data were not available from 1972 to1979. Climatic control underlies the data trend, thus two domains of attraction wet (coordinate 1980, 1981) and drought periods (1981 - 1996) are discriminated. Trajectories within the drought domain are aperiodic with no apparent domain(s) or points of stability.

Previous assessments of range condition and trend at Deseret were plot-based field surveys that focused on individual paddocks and thus failed to inform managers of the ecological condition and trajectory of the entire landscape. Remote sensing-based assessments complement field surveys by providing a synoptic view of landscapes. Consideration of the mean SAVI relative to the 1970's suggests Deseret's vegetation cover is in decline (Fig. 3). If the state of vegetation cover is used as an index of good management, then this trend is contrary to the assumption we had that the vegetation cover from 1972 to 1983 would be less than or equal to the vegetation cover from 1984 to 1997 because of a change to new and better management in 1983. However, when climate is considered, the downward trend corresponds primarily to wet and drought periods.

The aperiodic orbits and trajectories in Figure 3 present empirical evidence that a semi-arid sagebrush steppe landscape exhibits chaotic or non-equilibrial behavior (Fig. 1). Despite exceptionally wet years in 1983, 1986, and 1997, the landscape did not recover to 1970 conditions (Fig. 1). This suggests that a threshold had been exceeded in 1981 and that herbivory, wildfire, seeding, and other land management practices may be a factor in landscape vegetation cover recovery (Fig. 3 and Fig. 5). Wet years are more stable (high mean/low variance of vegetation cover) than dry years for management practices, but management practices in dry years may be crucial to intermittent wet years having the ability to return the landscape to the wet domain. The relationship between stocking rate and vegetation cover exhibits properties similar to discontinuously stable function (Case 4) or a fold catastrophe, i.e., the pattern suggests positive and negative feedbacks between stocking rate and vegetation cover. This study considered only a single index of vegetation cover. Future studies will consider indices related to landscape pattern changes and soil erosion.

Publications/Presentations:

West, N.E. 1997. How healthy are our rangelands? Forum for Applied Research and Public Policy 12 (3):145-146.

West, N.E. And E.L. Smith. 1997. Improving the monitoring of rangelands. Rangelands 19(6):9-14.

West, N.E. 1997. Landscape ecology approaches to rangeland monitoring. Invited talk at Idaho National Engineering and Environmental Laboratory, Sept. 10.

West, N.E., R.A.Washington-Allen, R.D. Ramsey, and Carolyn T. Hunsaker. 1998. Characterization of the ecological Integrity of commercially grazed rangelands using remote sensing-based ecological indicators. Program Review, STAR Grants, Ecological Assessment/Ecosystem Indicators, Environmental Protection Agency, Las Vegas, NV. Feb. 5.

Washington-Allen, R. A, N.E. West, R.D. Ramsey, and C.T. Hunsaker. 1998. A methodology for synoptic land condition and trend assessment of remote and inaccessible public lands. Poster Abstracts 51st Annual Meetings Society for Range Management, Guadalajara, Jalisco, Mexico, February 12-18, 1998. p. 36

West, N.E. And R.A.Washington-Allen. 1998. A new approach to monitoring whole ranches. Presentation to ranchers, extension agents, management and regulatory agency representatives, Castle Rock Ranch, Utah. May 20, 1998.

Washington-Allen, R. A. 1998. Assessment of disturbance impacts on ranch and military landscapes: A remote sensing and GIS perspective. Invited talk to Utah State University RS/GIS Laboratory, June 24.

Washington-Allen, R. A., N. E. West, R.D. Ramsey, and B.E. Norton. 1998. Remote sensing-based indicators of ecological resilience for rangelands. *Ecological Society of America Abstracts*, Poster, p. 226.

Future Activities:

We will complete the database, including production of soil attribute layers and digital elevation models, acquisition and scanning of aerial photos for accuracy assessment, and then we will proceed to concentrate on analyses. We will analyze the temporal and spatial behavior of remote sensing-based ecological indicators derived from a definition of rangeland degradation. Rangeland degradation is defined as a change in plant species composition; a decrease in plant productivity; a reduction in soil quality; accelerated soil erosion; and a change in landscape composition and pattern. The assessment of these indicators will occur at multiple scales including: landscape, watershed, administrative (i.e., public versus private land), individual paddock, ecological site, and piosphere (waterpoints). Continued extension activities will occur with Deseret's natural resource managers including transfer of Deseret's GIS database to CD-ROM for use by Deseret.

The following Talks and Posters will be given in the coming year:

Washington-Allen, R. A, N.E. West, R.D. Ramsey, and C.T. Hunsaker. 1999. Characterization of the ecological integrity of commercially grazed rangelands using remote sensing-based ecological indicators. Invited Paper/Talk: National Resources Conservation Service Workshop on Rangeland Health, Las Cruces, New Mexico, October 27 - 29, 1998.

Washington-Allen, Robert A., Thomas G. Van Niel, Brian Beach, and Paul M. Schwartz. 1999. An Automated Method for Atmospheric Correction of Satellite Imagery. Poster Annual Meeting of the American Society of Photogrammetry and Remote Sensing, Portland, Oregon.

West, N.E. 1999. Accounting for rangeland resources over entire landscapes. Invited Plenary Talk, International Rangelands Congress, Townsville, Queensland, Australia.

Washington-Allen, R. A, N.E. West, R.D. Ramsey, and C.T. Hunsaker. 1999. Characterization of the Ecological Integrity of Commercially Grazed Rangelands Using Remote Sensing-Based Ecological Indicators. Poster, International Rangelands Congress, Townsville,

Queensland, Australia.

Other talks, demonstrations, and posters will be given at the Ecological Society of America, the International Association of Landscape Ecology and the ESRI meetings. Peer-reviewed papers will be targeted primarily towards: Ecological Applications, Journal of Range Management, Journal of Applied Ecology, and Journal of Arid Environments.

Supplemental keywords: rangeland health, rangeland condition, landscape metrics.

Relevant web sites:

A web site is under development and is currently located at the password protected URL: www.esd.ornl.gov/preview/obq/

Table 1. Summary of GIS data available to characterize the natural resources of Deseret Land and Livestock Ranch.

Theme	Attributes	Dates	Spatial Coverage	Resolution/Spatial Error Estimate	Data Type	Reference
Vegetation Cover	31 Vegetation Cover Types and 5 Land Use Types based on UNESCO Hierarchichal classification system	June -July 1984 - 1993	Utah Entire State	100 ha minimal mapping unit (MMU) Riparian and Wetland have 40 ha MMU	Raster Map derived from mosaiced Landsat Thematic Mapper Scences (acquired from Utah Gap Analysis Project), UTM Projection, NAD 27	**Edwards, Jr., T.C., C.G. Homer, S.D. Bassett, A. Falconer, R.D. Ramsey, and D.W. Wight. 1995.** *Utah Gap Analysis: An Environmental Information System.* Final Project Report 95-1, Utah Cooperative Fish and Wildlife Research Unit, Utah State University, Logan, Utah 84322-5210.
Land Thematic Mapper Imagery	7-Band sensed image (Infrared x 3, thermal red, green, and blue), 8 bit Raster	July 1986 - September 1998	180 km x 180 km scene Path 38 Row	30 m resampled to 57 m	Raster Landsat Thematic Mapper (TM) 7 x 8-bit bands raster image, full scenes acquired from EROS Data Center, UTM Projection, NAD 27	Receiving Station: USGS EROS Data Center, SD, USA Earth Observation Satellite Company, 1985, User's guide for Landsat thematic mapper computer-compatible tapes: Lanham, Md., Earth Observation Satellite Company [variously paged]. Earth Observation Satellite Company, 1994, Landsat system status report--September 1994: Lanham, Md., Earth Observation Satellite Company, p. 1-11.
Digital Elevation Model (DEM)	Topographic map hypsography overlay	1992	7.5 Minute Quadrangle	30 m A vertical RMSE of 7 m - 15 m	Level-1 DEM scanned from NHAP/NAPP aerial photography or from digitized contour lines from cartographic maps, Single band, 16-bit Digital Elevation Model (DEM), UTM Projection, NAD 27	U.S. Geological Survey, 1993, Digital elevation models --data users guide 5: Reston, Virginia, U.S. Geological Survey, 48 p. U.S. Geological Survey, 1993, US GeoData digital elevation model, factsheet: [Reston, Virginia], U.S. Geological Survey, 2 p.
Landsat Multi spectral Imagery	4-Band sensed image (Infrared x 2, red and green), 6 and 7 bit Raster	September 1972 - September 1992	180 km x 180 km scene	25m	raster Landsat Multi spectral Scanner 4 x 6 and 7-bit bands raster image, full scenes acquired from EROS Data Center. UTM Projection, NAD 27 NALC: a Landsat MSS triplicate that is comprised of three dates of co-registered imagery and a DEM . Imagery were acquired in 1973, 1986, and 1991 plus or minus one year. the DEM is 16-bit (INTEGER*2) data.	Receiving Station: USGS EROS Data Center, SD, USA Thomas, V.L., 1977, Generation and physical characteristics of the Landsat-1, -2 and -3 MSS computer compatible tapes: Greenbelt, Md., National Aeronautics and Space Administration, Goddard Space Flight Center, Technical Memorandum 78018 [variously paged] U.S. Geological Survey and National Oceanic and Atmospheric Administration, 1984, Landsat 4 data users handbook: [Washington, D.C.], U.S. Geological Survey and National Oceanic and Atmospheric Administration [variously paged]. Lunetta, R.S., and Sturdevant, J.A., 1993, The North American Landscape Characterization Landsat Pathfinder Project, in Pettinger, L.R., ed., Pecora 12 Symposium, Land Information from Space-Based Systems, Proceedings: American Society of Photogrammetry and Remote Sensing, Bethesda, Md., p. 363-371.
Geology	Formation	1980	Utah, Entire State	25m in raster	vector/polygon, UTM Projection, NAD 27, Hand digitized from 1:500,000 map	Hintze, L.F. (Compiler)1980. Geological Map of Utah. 1/500,000 colored with cross sections and stratigraphic columns. Published by compiler, Provo, Utah. Hand digitized by Utah State University R/S GIS Research Laboratory in 1992.
Soils	Soil series and related physical attributes from MUIR NRCS database.	1982	Rich County, Utah	1 ha	vector/polygon, UTM Projection, NAD 27	Digitized by Robert A. Washington-Allen from Rich County Soil Survey 1982 **Soil Conservation Service. 1982.** Soil Survey of Rich County, Utah. USDA. U.S. Government Printing Office, Washington, D.C. Joined to National Map Unit Interpretation Record (MUIR) database from NRCS for Rich County, Utah USDA-NRCS.1994. National Map Unit Interpretation Record (MUIR) Database Publication Information. USDA-NRCS, Ft. Worth, TX.
Soils	Soil associations and related physical attributes from STATSGO database	1982	United States of America	625 ha	vector/polygon, UTM Projection, NAD 27	USDA-NRCS State Soil Geographic Database (STATSGO) U.S. Department of Agriculture, 1994, State soil geographic (STATSGO) data base--data use information, miscellaneous publication number 1492 (rev. ed.): Fort Worth, Texas, Natural Resources Conservation Service [variously paged].
Roads	Primary Secondary Tertiary Trails Jeep roads	1,994	Utah, Entire State	within • 80 m	vector/line, UTM Projection, NAD 27	SGID Utah State Geographic Information Database by The Automated Geographic Reference Center (AGRC) a division of the State of Utah, Department of Administrative Services, Information Technology Services, Salt Lake City, Utah 84114, (801)538-3165
Grazing Paddocks	Paddock name joined to digital eighteen year livestock and sixteen year wildlife grazing management data.	1,998	88,000 ha	90% of data within • 40 ft	vector/line and polygon, UTM Projection, NAD 27	Digitized by Robert A. Washington-Allen from USGS 7.5 Min Topographic Maps 1976 and 1996

Table 1 (Continued..). Summary of GIS data available to characterize the natural resources of Deseret Land and Livestock Ranch.

Hydrology	Streams, ponds, and tributaries	1,994	Utah Entire State	within • 80 m	Vector/line and polygon, UTM Projection, NAD 27	SGID Utah State Geographic Information Database by The Automated Geographic Reference Center (AGRC) a division of the State of Utah, Department of Administrative Services, Information Technology Services, Salt Lake City, Utah 84114, (801)538-3165
Administrative Boundary	Desert ownership boundary	1994	88,000 ha	90% of data within • 40 ft	Vector/line and polygon, UTM Projection, NAD 27	Digitized by Robert A. Washington-Allen from USGS 7.5 Min Topographic Maps 1976 and 1996
Shrub Cover Density	Shrub density	1988	Rich County	30 m raster	Raster, UTM Projection, NAD 27	**Homer, C.G., T.C. Edwards, Jr, R.D. Ramsey, and K.P. Price. 1993.** Use of Remote Sensing methods in modeling sage grouse winter habitat. *Journal of Wildlife Management* 57:78-84.
Grass and Shrub Density Cover Map	Vegetation Density	1988	Rich County	30 m raster	Raster, UTM Projection, NAD 27	**Hunnicutt, M. 1992.** *Use of Landsat Imagery and Geographical Information Systems in the assessment of Rangeland Cover and Wildlife Habitat.* M.S. Thesis, Utah State University, Logan. USA.
Waterpoints	Location	1997	88,000 ha	90% of data within • 40 ft	Vector/point, UTM Projection, NAD 27	Digitized by Robert A. Washington-Allen from USGS 7.5 Min Topographic Maps 1976 and 1996
Utah_state _bnd	State Boundary	1994	Utah Entire State	90% of data within • 40 ft	Vector/line and polygon, UTM Projection, NAD 27	SGID Utah State Geographic Information Database by The Automated Geographic Reference Center (AGRC) a division of the State of Utah, Department of Administrative Services, Information Technology Services, Salt Lake City, Utah 84114, (801)538-3165
Rich_Bnd	County Boundary	1994	Entire County	90% of data within • 40 ft	Vector/line and polygon, UTM Projection, NAD 27	SGID Utah State Geographic Information Database by The Automated Geographic Reference Center (AGRC) a division of the State of Utah, Department of Administrative Services, Information Technology Services, Salt Lake City, Utah 84114, (801)538-3165
aerial photographs	B&W and Colour IR	1972 - 1997	indexed on 1:100000 - 250000 map reference sheets	1 -2 meter object resolution	Analog B&W Analog CIR aerial photo Analog Orthophotoquadrangle , UTM Projection, NAD 27	U.S. Geological Survey, 1992, The National Aerial Photography Program (NAPP), factsheet: Reston, Virginia, U.S. Geological Survey, 1 p. U.S. Geological Survey, 1992, NHAP and NAPP photographic enlargements, factsheet: Reston, Virginia, U.S. Geological Survey, 1 p.

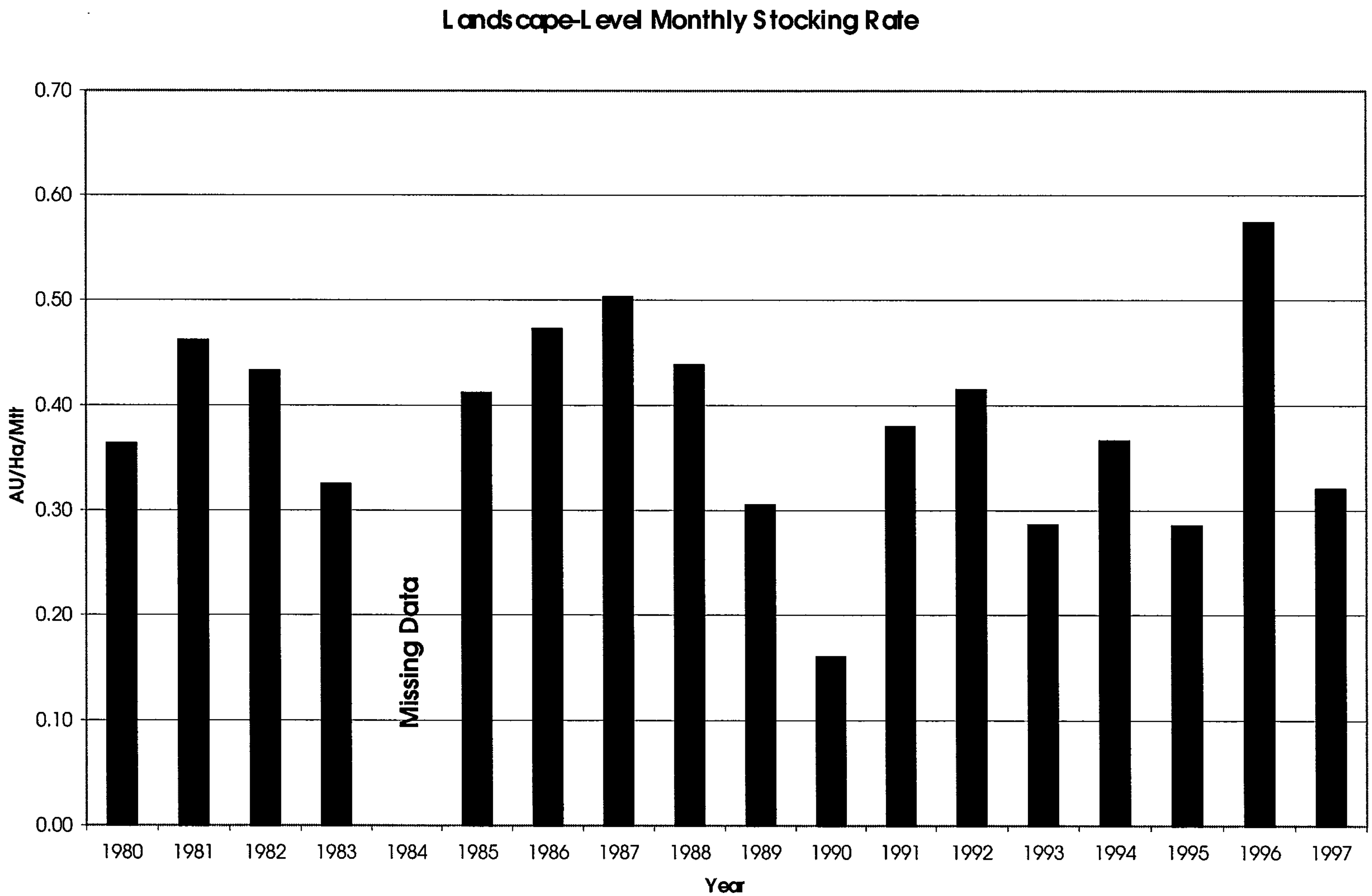


Figure 1. The Animal Unit Month (AUM) per hectare for Deseret Land & Livestock Ranch from 1980 to 1997.

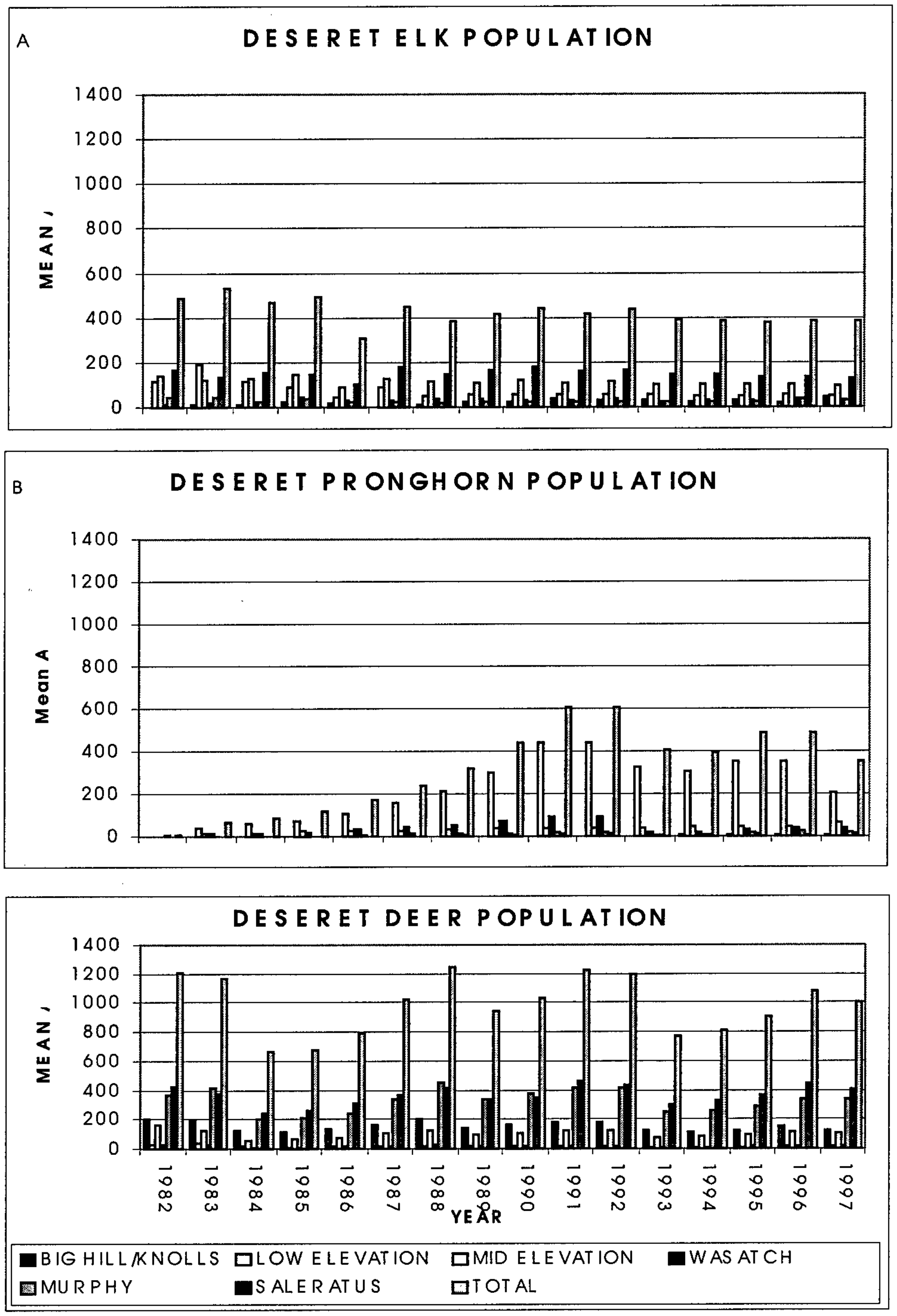
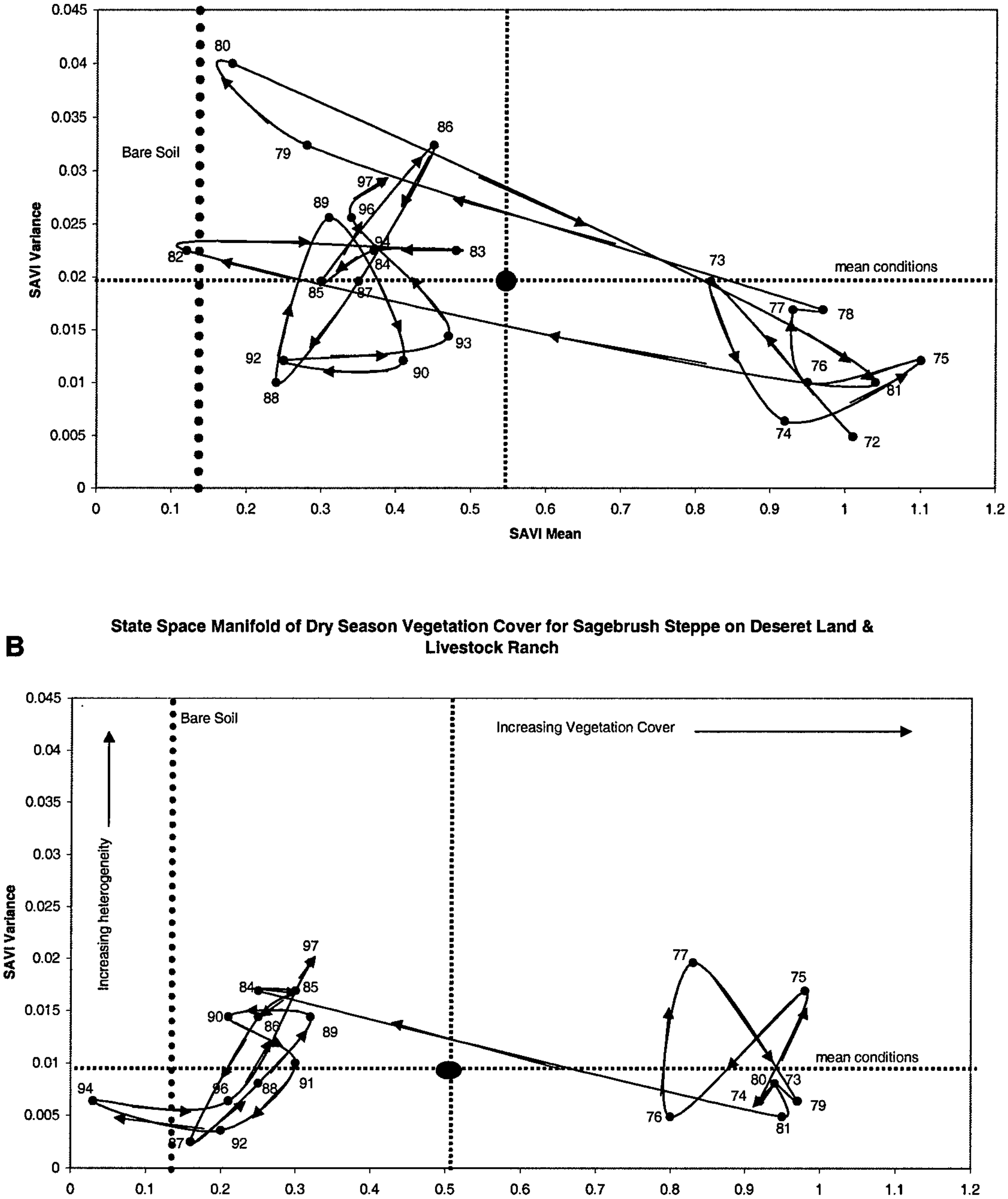


Figure 2. Population of elk (A), pronghorn (B), and deer (C) on Deseret Land & Livestock Ranch from 1982 - 1997.

A



B

Figure 3. Mean/Variance plots of the Wet and Dry Season Soil Adjusted Vegetation Index (SAVI). SAVI indicates the amount of vegetation cover on the ranch where high variance and low mean years are indicative of drought and increased susceptibility to accelerated soil erosion.

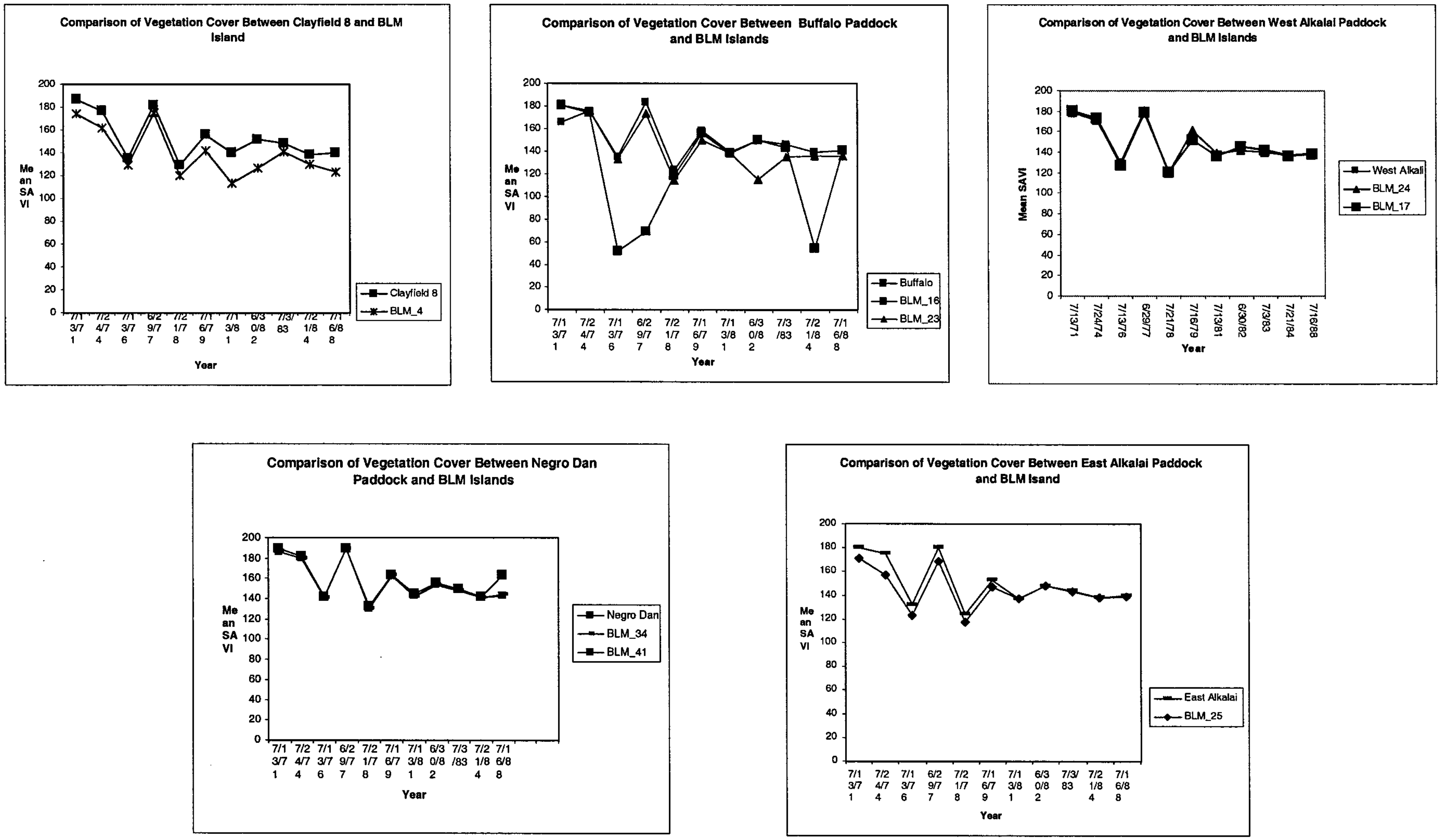


Figure 4. Comparison from 1975 to 1992 of the soil adjusted vegetation index (SAVI), an index of vegetation cover, between Bureau of Land Management land islands and the private land which contains them.

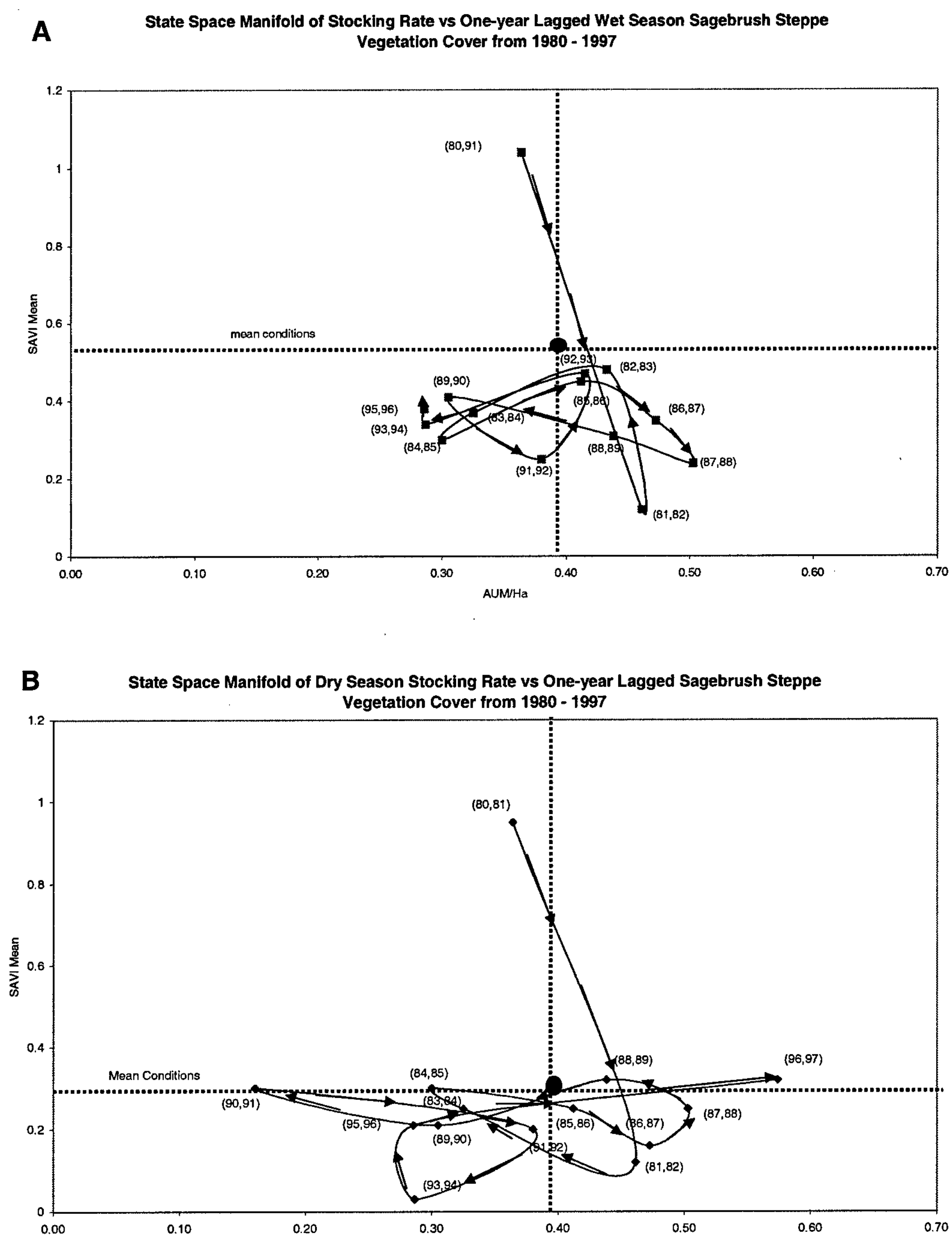


Figure 5. Comparison of wet (A) and dry (B) season livestock stocking rate to one-year lagged vegetation cover [SAVI, (the soil-adjusted vegetation index, a surrogate measure of vegetation cover)]. Stocking data from 1972 to 1979 was not available, but vegetation cover during this period was comparable to the (1980,1981) coordinate (see Fig. 1). Consequently, two domains are discriminated which correspond to wet and drought years on the ranch and one major threshold between domains at the (1980,1981) coordinate. Missing data are interpolated.

APPENDIX 2 – Field Data Sheets

Table 1. Ground vegetation data for Camp Williams site #1 transect.

200 series	a#1		camp williams		Camp Williams		
Site A#1							
Species	Transect 1	Transect2	Transect3	Transect 1	Transect2	Transect3	Total
rock		5.00	15.00	0.00	0.10	0.30	20
Bromus tectorum	432.00	1200.00	1110.00	8.55	23.76	21.98	2742
Gutierrezia sarothrae	596.00	110.00	330.00	11.80	2.18	6.53	1036
Chrysothamnus nauseosus		20.00		0.00	0.40	0.00	20
Artemisia tridentata	1090.00	775.00	1495.00	21.58	15.35	29.60	3360
litter	364.00	225.00	310.00	7.21	4.46	6.14	899
moss	44.00			0.87	0.00	0.00	44
Poa bulbosa	95.00	590.00	255.00	1.88	11.68	5.05	940
Forb	91.00	120.00	45.00	1.80	2.38	0.89	256
standing dead	15.00	465.00	215.00	0.30	9.21	4.26	695
Eriogonum sp.	145.00	150.00		2.87	2.97	0.00	295
Artemisia sp.			55.00	0.00	0.00	1.09	55
TOTAL COVER				56.87	72.48	75.84	
Site A#2	Site a#2						
Species	Transect 1	Transect2	Transect3	Transect1	Transect 2	Transect 3	Total
rock	8.00	85.00		0.16	1.68	0.00	0.613
Bromus tectorum	400.00	175.00	364.00	7.92	3.47	7.21	6.198
Salsola tragus	10.00			0.20	0.00	0.00	0.066
Gutierrezia sarothrae	440.00	395.00	838.00	8.71	7.82	16.59	11.04
Chrysothamnus nauseosus	60.00			1.19	0.00	0.00	0.396
Oryzopsis hymenoides	10.00			0.20	0.00	0.00	0.066
Artemisia tridentata	65.00	235.00	265.00	1.29	4.65	5.25	3.729
litter	510.00	682.00	810.00	10.10	13.50	16.04	13.21
Agropyron spicatum	550.00	445.00	350.00	10.89	8.81	6.93	8.877
Poa pratentsis	35.00	55.00	38.00	0.69	1.09	0.75	0.844
Forb	95.00	175.00		1.88	3.47	0.00	1.782
standing dead	30.00	95.00	120.00	0.59	1.88	2.38	1.617
Artemisia sp.			30.00	0.00	0.00	0.59	0.198
Poa bulbosa	385.00		490.00	7.62	5.49	9.70	5.775
Astragalus sp.	20.00	180.00		0.40	3.56	0.00	1.320

Erodiun cicutarium	10.00			0.20	0.00	0.00	0.066
curly cup		45.00	95.00	0.00	0.89	1.88	0.924
TOTAL COVER				52.04	56.32	67.33	56.73

Site B#1							
Species	Transect 1	Transect2	Transect3	Transect1	Transect 2	Transect 3	Total
rock		3.00	595.00	0.00	0.06	11.78	3.947
Bromus tectorum	385.00	462.00	795.00	7.62	9.15	15.74	10.83
Salsola tragus	70.00			1.39	0.00	0.00	0.462
Gutierrezia sarothrae	447.00	314.00		8.85	6.22	0.00	5.023
Artemisia tridentata	590.00	995.00	1185.00	11.68	19.70	23.47	18.28
litter	265.00	442.00	120.00	5.25	8.75	2.38	5.458
Agropyron spicatum			135.00	0.00	0.00	2.67	0.891
Poa pratensis			128.00	0.00	0.00	2.53	0.844
Forb	34.00		78.00	0.67	0.00	1.54	0.739
standing dead	68.00	105.00	80.00	1.35	2.08	1.58	1.669
Artemisia sp.			15.00	0.00	0.00	0.30	0.099
Poa bulbosa	315.00	657.00	100.00	6.24	13.01	1.98	7.075
curly cup	66.00	67.00		1.31	1.33	0.00	0.877
Verbasscu m thapsus			60.00	0.00	0.00	1.19	0.396
TOTAL COVER				44.36	60.30	65.17	56.60

Site B#2							
Species	Transect 1	Transect2	Transect3	Transect1	Transect 2	Transect 3	Total
rock	290.00	916.00	595.00	5.74	18.14	11.78	11.88
Bromus tectorum	1061.00	695.00	795.00	21.01	13.76	15.74	16.83
Salsola tragus	105.00			2.08	0.00	0.00	0.693
Artemisia tridentata	1620.00	860.00	1185.00	32.08	17.03	23.47	24.19
litter	301.00	250.00	120.00	5.96	4.95	2.38	4.429
Agropyron spicatum	20.00		40.00	0.40	0.00	0.79	0.396
Poa pratentsis	15.00	105.00	128.00	0.30	2.08	2.53	1.636
Forb	38.00	185.00	30.00	0.75	3.66	0.59	1.669
standing dead	88.00	140.00	80.00	1.74	2.77	1.58	2.033
Artemisia sp.	30.00			0.59	0.00	0.00	0.198
Poa bulbosa	27.00	230.00	100.00	0.53	4.55	1.98	2.356
TOTAL COVER				71.19	66.95	60.85	66.33

Site C #1							

Species	Transect 1	Transect2	Transect3	Transect 1	Transect 2	Transect 3	Total
rock	705.00	865.00	840.00	13.96	17.13	16.63	15.90
Bromus tectorum	895.00	965.00	1170.00	17.72	19.11	23.17	20
Salsola tragus	20.00			0.40	0.00	0.00	0.132
Chrysothamnus nauseosus			15.00	0.00	0.00	0.30	0.099
Artemisia tridentata	390.00	280.00	450.00	7.72	5.54	8.91	7.392
litter	920.00	1015.00	920.00	18.22	20.10	18.22	18.84
Agropyron spicatum	315.00	340.00	175.00	6.24	6.73	3.47	5.478
Poa pratentsis	375.00	220.00	155.00	7.43	4.36	3.07	4.950
Poa bulbosa	55.00			1.09	0.00	0.00	0.363
Forb	40.00	10.00	15.00	0.79	0.20	0.30	0.429
standing dead	55.00	80.00	60.00	1.09	1.58	1.19	1.287
Artemisia	15.00	10.00		0.30	0.20	0.00	0.165
Eriogonum sp.	110.00	335.00	160.00	2.18	6.63	3.17	3.993
Leymus elymoides	200.00	130.00	240.00	3.96	2.57	4.75	3.762
Artemisia sp.	206.00	315.00	70.00	4.08	6.24	1.39	3.900
TOTAL COVER				85.17	90.40	84.55	86.70

Site C #2							
Species	Transect 1	Transect2	Transect3	Transect1	Transect 2	Transect 3	Total
rock		675.00	840.00	0.00	13.37	16.63	10
Bromus tectorum		10.00	1200.00	0.00	0.20	23.76	7.986
Chrysothamnus nauseosus			15.00	0.00	0.00	0.30	0.099
Artemisia tridentata	2620.00	2295.00	2980.00	51.88	45.45	59.01	52.11
Litter	490.00	475.00	1475.00	9.70	9.41	29.21	16.10
Agropyron spicatum	385.00	520.00	660.00	7.62	10.30	13.07	10.33
Poa pratentsis			155.00	0.00	0.00	3.07	1.023
Poa bulbosa	50.00	20.00	5.00	0.99	0.40	0.10	0.495
Forb			15.00	0.00	0.00	0.30	0.099
standing dead	150.00	380.00	125.00	2.97	7.52	2.48	4.323
Eriogonum sp.	30.00	40.00	160.00	0.59	0.79	3.17	1.518
Artemisia sp.			70.00	0.00	0.00	1.39	0.462
TOTAL COVER				73.76	87.43	152.48	104.5

Table 2. Ground vegetation data for Camp Williams site #2 Transect.

Camp Williams Region V

Site A#1

Species	Transect 1	Region V Transect 2	Camp Williams Transect 3	Transect 1	Transect 2	Transect 3	Combined
rock	912.00	125.00	200.00	18.06	2.48	3.96	8.22
Bromus tectorum		10.00	105.00	0.00	0.20	2.08	0.76
Gutierezzia sarothrae	30.00	15.00	30.00	0.59	0.30	0.59	0.50
Chrysothamn us nauseosus		40.00		0.00	0.79	0.00	0.27
Oryzopsis hymenoides	10.00	80.00	45.00	0.20	1.58	0.89	0.90
Artemisia tridentata	755.00	750.00	1260.00	14.95	14.85	24.95	18.37
Litter	630.00		595.00	12.48	0.00	11.78	8.14
Agropyron cristatum	350.00	900.00	235.00	6.93	17.82	4.65	9.87
Poa pratensis				0.00	0.00	0.00	0.00
Poa bulbosa	660.00	250.00	240.00	13.07	4.95	4.75	7.64
Standing dead	55.00	225.00	50.00	1.09	4.46	0.99	2.19
Eriogonum sp.		5.00	20.00	0.00	0.10	0.40	0.17
Elymus elymoides		15.00		0.00	0.30	0.00	0.10
TOTAL COVER				67.37	47.82	55.05	57.12

Site B#2

Species	Transect 1	Transect 2	Transect 3	Transect 1	Transect 2	Transect 3	Combined
rock	1350.00	810.00	1090.00	26.73	16.04	21.58	21.59
Bromus tectorum	840.00	390.00	455.00	16.63	7.72	9.01	11.20
THISTLE				0.00	0.00	0.00	0.00
Oryzopsis hymenoides			20.00	0.00	0.00	0.40	0.13
Artemisia tridentata		70.00	600.00	0.00	1.39	11.88	4.45
litter	685.00	620.00	580.00	13.56	12.28	11.49	12.52
Agropyron spicatum		160.00	160.00	0.00	3.17	3.17	2.13
Poa pratentsis			20.00	0.00	0.00	0.40	0.13
Poa bulbosa				0.00	0.00	0.00	0.00
Forb		20.00	10.00	0.00	0.40	0.20	0.20
standing dead	230.00	230.00	5.00	4.55	4.55	0.10	3.09
Eriogonum sp.	80.00	20.00	25.00	1.58	0.40	0.50	0.83
Leymus elymoides		75.00	80.00	0.00	1.49	1.58	1.03
Juniperus osteosperma	800.00	900.00	200.00	15.84	17.82	3.96	12.62
TOTAL COVER				78.91	65.25	64.26	69.93

Site B#3

Species	Transect 1	Transect 2	Transect 3	Transect 1	Transect 2	Transect 3	Combined
rock	20.00	380.00	285.00	0.40	7.52	5.64	4.55
Bromus tectorum	50.00	10.00	15.00	0.99	0.20	0.30	0.50
Gutierrezia sarothrae	10.00	25.00		0.20	0.50	0.00	0.23
Oryzopsis hymenoides	20.00	20.00	10.00	0.40	0.40	0.20	0.33
Litter	310.00	180.00	155.00	6.14	3.56	3.07	4.29
Agropyron spicatum	5.00	70.00	5.00	0.10	1.39	0.10	0.53
standing dead			10.00	0.00	0.00	0.20	0.07
Eriogonum sp.	5.00		15.00	0.10	0.00	0.30	0.13
Juniperus osteosperma	1550.00	2750.00	2850.00	30.69	54.46	56.44	47.51
TOTAL COVER				39.01	68.02	66.24	58.14

Site C#1

Region V

Species	Transect 1	Transect 2	Transect 3	Transect 1	transect 2	transect 3	combined
rock	5.00			0.10	0.00	0.00	0.03
Bromus tectorum	50.00	455.00	595.00	0.99	9.01	11.78	7.31
Chrysothamnus nauseosus	85.00	100.00	85.00	1.68	1.98	1.68	1.79
litter	100.00	1710.00	1620.00	1.98	33.86	32.08	22.79
Forb	42.00	125.00	35.00	0.83	2.48	0.69	1.34
Artemisia sp.	50.00			0.99	0.00	0.00	0.33
Halogeton glomeratus	355.00		100.00	7.03	0.00	1.98	3.02
Astragalus beckwithii	365.00	285.00	555.00	7.23	5.64	10.99	8.01
Marrubium vulgare	65.00		35.00	1.29	0.00	0.69	0.66
Stipa comata	10.00	200.00	90.00	0.20	3.96	1.78	1.99
TOTAL COVER				22.32	56.93	61.68	47.29

Site D #1

RegionV

Species	Transect 1	Transect 2	Transect 3	Transect 1	Transect 2	Transect 3	Combined
Bromus tectorum	6300.00	2725.00		124.75	53.96	0.00	59.97
Salsola tragus	2.00	50.00		0.04	0.99	0.00	0.35
Chrysothamnus nauseosus	30.00			0.59	0.00	0.00	0.20
litter	1180.00			23.37	0.00	0.00	7.84
Forb		10.00		0.00	0.20	0.00	0.07
standing dead	40.00			0.79	0.00	0.00	0.27
Halogeton glomeratus		140.00	50.00	0.00	2.77	0.99	1.26
Astragalus beckwithii	910.00			18.02	0.00	0.00	6.05
Stipa comata	30.00			0.59	0.00	0.00	0.20
Castilleja chromosa			275.00	0.00	0.00	5.45	1.83
Descurainia sp.			240.00	0.00	0.00	4.75	1.59

TOTAL COVER				168.16	57.92	11.19	79.61

Site D #2 Region V

Species	Transect 1	Transect 2	Transect 3	Transect 1	Transect 2	Transect 3	Combined
Bromus tectorum	1240.00	2090.00	1300.00	24.55	41.39	25.74	30.76
Chrysothamnus nauseosus			1162.00	0.00	0.00	23.01	7.72
Litter	1035.00	1990.00	940.00	20.50	39.41	18.61	26.35
standing dead	100.00			1.98	0.00	0.00	0.66
Artemisia sp.	80.00			1.58	0.00	0.00	0.53
Halogeton glomeratus	1555.00	370.00	395.00	30.79	7.33	7.82	15.42
Astragalus beckwithii	295.00		10.00	5.84	0.00	0.20	2.03
Stipa comata		20.00		0.00	0.40	0.00	0.13
Castilleja chromosa	860.00	260.00		17.03	5.15	0.00	7.44
Descurainia sp.	65.00			1.29	0.00	0.00	0.43
TOTAL COVER				103.56	93.66	75.39	91.48

Table 3. Ground vegetation data for Camp Williams site #3 transect.

Site A#1	Camp Williams			Tickville
Species	**Transect 1**	**Transect 2**	**Transect 3**	**Combined**
Rock	0.13%	6.93%	6%	6.73%
Bromus tectorum	5.15%	9.01%	12.87%	12%
Salsola tragus	0.40%	3.07%	6.24%	4.82%
Gutierezzia sarothrae	5.94%	0.40%	1.98%	0.93%
Chrysothamnus nauseous	5.74%	4.36%	9.11%	6.47%
Eriogonum sp.	0.40%	9.60%	5.64%	7.00%
Oryzopsis hymenoides	1.98%	0.99%	1.98%	1.12%
Artemisia tridentata	0.99%	0	0	0.66%
Opuntia	19.60%	0	1.19%	0.73%
Burnt Juniper	10.69%	18.61%	10.10%	0.16%
Litter	1.39%	8.81%	7.43%	8.98%
Purshia tridentata	0	2.77%	1.19%	1.78%
Verbascum thapsus	0	1.09%	0.89%	0.66%
Leymus elymoides	0	0.59%	0	0.20%
Stipa comata	0	0	1.39%	0.46%
Wastach sage	0	0	0.59%	0.20%
TOTAL COVER	52.41%	66.24%	66.59%	53%

Site A#2				Tickville
Species	**Transect 1**	**Transect 2**	**Transect 3**	**Combined**
Rock	7.92%	4.75%	5.35%	6.01%
Bromus tectorum	5.45%	3.86%	2.18%	3.83%
Tragus salsola	1.68%	0.20%	0	0.63%
Eriogonum sp.	0.59%	0.99%	0	0.53%
Oryzopsis hymenoides	2.57%	1.78%	10.30%	4.88%
Burnt Juniper	8.12%	6.14%	5.94%	6.73%
Litter	10.50%	20%	14.55%	15.02%
Gutierrezia sarothrae	14.06%	9.50%	12.99%	12.18%
Verbascum thapsus	0.79%	5.54%	0.20%	2.18%
Leymus elymoides	1.09%	0	0	0.36%
Quercus gambelii	21.98%	29.70%	33.66%	28.45%
Agropryon spicatum	0.99%	0	0	0.33%
Marrubium vulgare	0.40%	0	0	0.13%
Moss	0	0.40%	0	0.13%
Poa pratensis	0	0	0.79%	0.26%
TOTAL COVER	76.14%	82.87%	85.96%	81.66%

Table 4. Ground vegetation data for Ft. Bliss B site 2 transect.

B site02				
Species	transect 1	Transect 2	Transect 3	combined
Pectis lemonii	5.9%	2.2%	17.9%	8.7%
Aristida purpurea	5.7%	14.7%	4.3%	8.2%
Bouteloua eriopoda	11.0%	4.6%	2.6%	6.0%
Zinnia spp.	5.9%	4.2%	3.1%	4.4%
Green forb	2.0%	5.2%	4.6%	3.9%
Sporobolus flexuosus	4.0%	4.7%	0.4%	3.0%
Muhlenbergia porteri	2.0%	0.4%	1.8%	1.4%
Gutierrezia sarothrae	0.8%	1.8%	0.6%	1.1%
Litter	0.8%	1.0%	1.0%	0.9%
Prosopsis glandulosa	0.4%	---	2.0%	0.8%
Salsola kali	---	0.4%	1.2%	0.5%
Erioneuron pulchellum	1.4%	---	0.2%	0.5%
Bouteloua gracilis	0.4%	0.2%	---	0.2%
Panicum obtusum	0.6%	---	---	0.2%
Standing dead	---	0.4%	0.2%	0.2%
Total cover	40.8%	39.5%	39.7%	40.2%

Table 5. Ground vegetation data for Ft. Bliss site 10 transect.

Burn site 10 a				
Species	Transect 1	Transect 2	Transect 3	Combined
Flourensia cernua	10.69%	8.51%	10.69%	9.97%
Hilaria mutica	6.53%			2.18%
Muhlenbergia porteri	3.56%		3.56%	1.19%
Scleropogon brevifolius	8.91%	15.74%	8.71%	9.87%
Standing dead	1.19%			0.40%
Litter	1.78%	18.91%		0.59%
Crptogams	13.86%		13.86%	15.54%
Larrea tridentata		5.94%		1.98%
Opuntia spp.		0.20%		0.07%
TOTAL COVER	46.53%	49.30%	36.83%	41.78%
Site 10b				
Species	Transect 1	Transect 2	Transect 3	Total
Larrea tridentata	2.18%	7.13%	1.58%	3.63%
Flourensia cernua	5.15%	3.17%	4.55%	4.29%
Hilaria mutica	6.34%	0		2.11%
Muhlenbergia porteri	0.79%	9.35%		0.26%
Scleropogon brevifolius	6.04%	9.35%	5.25%	6.88%
Prosopis glandulosa	0.20%			0.07%
Litter	3.66%	3.56%	6.73%	4.65%
Crtptogams	2.77%	9.60%	6.44%	3.07%
Standing dead	2.18%	3.96%	2.67%	2.94%
TOTAL COVER	29.30%	46.11%	27.23%	27.90%

Table 6. Ground vegetation data for Ft. Bliss site 3 transect.

		Site #3A		
Species	**Transect1**	**Transect 2**	**Transect 3**	**Combined**
Mulenbergia porteri	4.16%	13.96%	6.73%	24.85%
Kramaria spp.	7.03%	5.35%	10.99%	23.37%
Larrea tridentata	4.16%	9.50%	1.39%	15.05%
Litter	2.38%	2.57%	3.47%	8.42%
Baileya multiradiata	3.96%	0.59%		4.55%
Standing dead	0.59%	3.07%	4.16%	7.82%
Forb	0.99%		1.39%	2.38%
Setaria	0.20%		0.40%	0.59%
Rock	0.30%	0.20%		0.50%
Sporobolus flexuosus	0.40%		2.67%	3.07%
Opuntia spp		5.94%	1.78%	7.72%
Cryptogams		0.10%		0.10%
TOTAL COVER	24.16%	41.28%	32.97%	98.41%

	Site #3B			
Species	**Transect 1**	**Transect 2**	**Transect 3**	**Combined**
***Krameria* sp.**	6.53%	8.12%	5.74%	20.39%
Baileya multiradiata	5.05%	2.97%	0.40%	8.42%
Aristida purpurea	0.50%	5.15%	6.73%	12.38%
***Cassia*sp.**	2.48%	3.17%	1.78%	7.43%
Litter	0.79%	0.50%	0.79%	2.08%
***Tridens* sp.**	0.20%	0.20%	0.10%	0.50%
Forb	0.20%	0.20%	0.20%	0.60%
***Zinnia*sp.**			1.78%	1.78%
***Eriogonum*sp.**	0.20%	0.99%		1.19%
Yucca elata			1.58%	1.58%
Standing dead		0.20%	1.49%	1.68%
TOTAL COVER	15.94%	21.49%	20.59%	58.02%

	Site #3C			
SPECIES	**TRANSECT1**	**TRANSECT 2**	**TRANSECT 3**	**COMBINED**
Prosopsis glandulosa	2.18%	15.25%	23.96%	13.80%
Standing dead	3.96%	1.78%	0.20%	1.98%
Larrea tridentata	9.31%	7.52%	3.96%	6.93%
Litter	3.37%	1.58%	3.56%	2.84%
Gutierrezia sarothrae	0.59%	1.98%		0.86%
TOTAL COVER	19.40%	28.12%	31.68%	26.40%

Table 7. Ground vegetation data for Ft. Bliss site 4 transect.

SITE 04,C				
Species	Transect 1	Transect 2	Transect 3	Combined
Scleropogon brevifolius	11.18%	10.59%	6.34%	9.37%
Scleropogon brevifolius	9.70%	6.53%		
	9.30%	0.59%	11.32%	11.32%
Bouteloua gracilis	0.40%	12.77%	1.78%	5.87%
Bouteloua eriopoda	1.49%	0.99%	0.99%	0.53%
Sporobolus flexuousus	0.40%			0.13%
Litter	0.20%	0.69%		0.89%
Muhlenbergia sp.	0.59%		0.20%	0.13%
Fluff grass	0.20%	0.10%	0.10%	1.65%
Solanum eleagnifolium	33.47%			0.20%
Cryptogams	0	33.62%	0.20%	0.23%
Forb		0.26%	1.39%	0.69%
Gutierrezia sarothrae		0.79%	1.78%	0.68%
Aristida purpurea			2.18%	0.73%
Opuntia spp.			0.30%	0.03%
TOTAL COVER	66.91%	66.95%	26.56%	32.46%
SITE 04 D				
Species	Transect 1	Transect 2	Transect 3	Combined
Bouteloua eriopoda	41.49%			28.68%
Bouteloua eriopoda	3.37%	21.19%		
Bouteloua eriopoda	0.79%		23.37%	
Bouteloua gracilis	0.59%	1.58%	3.17%	2.71%
Bouteloua hirsuta	0.20%	0.40%	8.42%	3.20%
Scleropogon brevifolius	1.78%			0.02%
	1.78%			
Sporobolus flexuousus	0.40%	1.78%	2.18%	1.91%
Forb	0.79%	1.39%	0.20%	1.12%
Cassia sp.	1.58%			0.13%
Litter	0.20%	0.59%	1.09%	0.83%
Aristida purpurea	0.50%	1.78%	0.20%	1.12%
Muhlenbergia porteria	53.47%	0.10%	1.58%	0.92%
Gutierrezia sarothrae		4.75%	1.88%	2.38%
		0.40%	0.40%	0.33%
Sporobolus cryptandrus		0.79%		0.13%
Sporoboalus airoides		0.40%		0.13%
Standing dead		1.19%		0.40%
Pectis lemonii			0.59%	0.02%
TOTAL COVER	106.93%	36.34%	43.07%	44.03%

Table 8. Ground vegetation data for Ft. Bliss site.

A site02				
Species	**transect 1**	**transect 2**	**transect 3**	**combined**
Hilaria mutica	**56.2%**	**81.8%**	**82.1%**	**73.4%**
***Amaranthus* spp.**	**10.3%**	**2.0%**	**0.6%**	**4.3%**
***Helianthus* spp.**	**12.3%**	**---**	**---**	**4.1%**
Green forb	**3.0%**	**5.9%**	**1.0%**	**3.3%**
Salsola kali	**9.5%**	**---**	**---**	**3.2%**
Cucurbita foetidissima	**---**	**3.8%**	**---**	**1.3%**
Panicum obtusum	**---**	**---**	**4.0%**	**1.0%**
Standing dead	**3.0%**	**0.6%**	**---**	**1.0%**
Scleropogon brevifolius	**---**	**2.4%**	**---**	**0.8%**
Litter	**---**	**0.6%**	**1.2%**	**0.6%**
TOTAL COVER	**94.0%**	**96.0%**	**89.0%**	**93.2%**